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ABSTRACT

This study guide is part of a program of studies entitled Science and Engineering Technician (SET) Curriculum. The SET Curriculum integrates elements from the disciplines of chemistry, physics, mathematics, mechanical technology, and electronic technology with the objective of training technicians in the use of electronic instruments and their applications. The following topics are included: (1) welding; (2) soldering and brazing; (3) plastics fabrication; (4) tubing and piping fabrication; (5) materials, properties and testing; (6) heat treating; and (7) finishes. (Author/SK)

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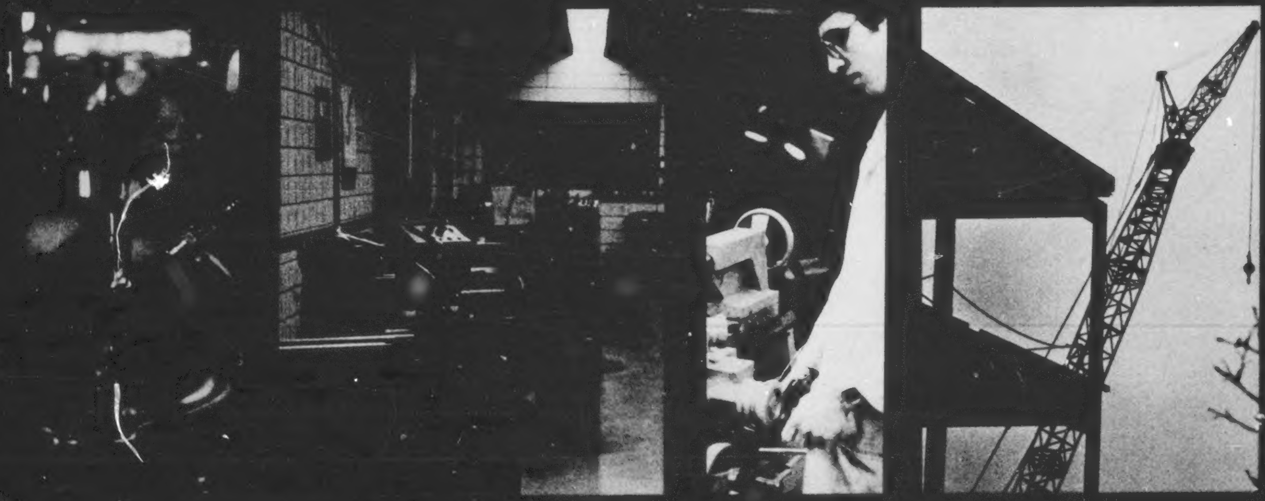
Materials and Fabrication Methods 2



A study guide of the Science and Engineering Technician Curriculum

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2

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15. Abstract

This study guide is part of a program of studies entitled the Science and Engineering Technician Curriculum. The SET curriculum integrates elements from the disciplines of chemistry, physics, mathematics, mechanical technology, and electronic technology, with the objective of training technicians in the use of electronic instruments and their applications.

The following topics are included in Materials and Fabrication Methods 2: (1) welding, soldering and brazing; (2) plastics fabrication; (3) tubing and piping fabrication; (4) materials, properties and testing; (5) heat treating; and (6) finishes.

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AND
FABRICATION METHODS II

A STUDY GUIDE
OF
THE SCIENCE AND ENGINEERING TECHNICIAN
CURRICULUM

Author: Andrew Lindberg, P.E.
St. Louis Community College at Florissant Valley

With assistance of:

Robert Bay
St. Louis Community College at Florissant Valley

Project Directors: Bill G. Aldridge
Donald R. Mowery
Lawrence J. Wolf

Study Guide Editor: Peggy Dixon
Montgomery College, Takoma Park, MD

Address: SET Project
St. Louis Community College at Florissant Valley
St. Louis, Missouri 63135

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CHAPTER I

WELDING, SOLDERING AND BRAZING

Section 1 - Introduction

Welding is the process of fusing together two pieces of material of the same or nearly the same material composition. Filler metal may be added to increase the weld area and joint strength. Clean metal surfaces improve the fusion process. Fluxes are used to reduce oxidation of the heated metal and remove impurities from the molten weld metal.

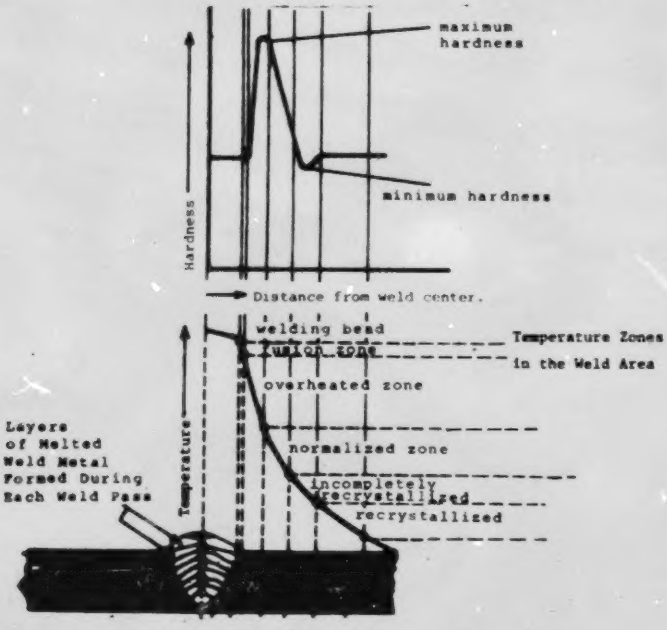
Welding affects the hardness and strength of the metal near the weld zone. The heat from welding leaves a metal area that may have a different crystal structure which results in reduced strength and hardness for the final fabricated part.

Hardness is a measure of a material's resistance to penetration. Hardness is a good indicator of a metal being susceptable to cracking under cyclic loading. Hardness also indicates the metal's strength.

Note the result of overheating a steel which can be heat treated. The overheated metal, upon fast cooling, becomes much harder. The weld area also has a zone which has less hardness and strength than the metal pieces being welded together. The heat from the weld operation has reduced the metal's strength and hardness.

We will learn later that another heat treating after welding can control the weld area crystal structure.

Below is shown the influence of welding heat on the distribution of hardness in the heat-affected zone of quenched and tempered structural steels.

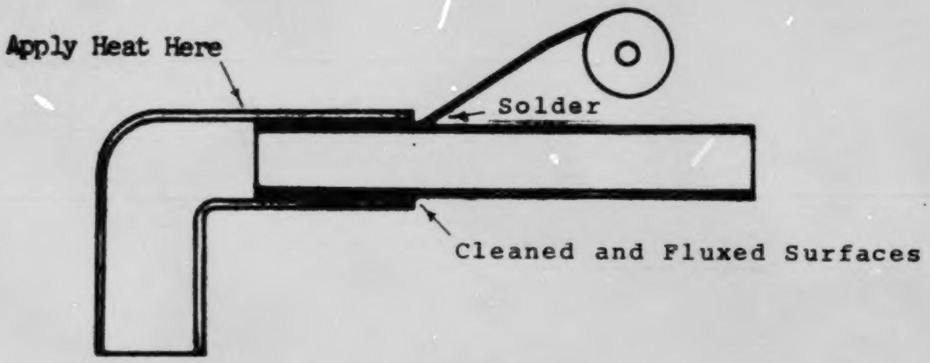

maximum hardness
minimum hardness
Hardness
Distance from weld center.
welding bead
fusion zone
overheated zone
normalized zone
incompletely recrystallized
recrystallized
Temperature Zones in the Weld Area
Temperature
Layers of Melted Weld Metal Formed During Each Weld Pass

SOLDERING

Soft soldering is the process of joining two pieces of metal with a metal alloy which melts below 427°C (800°F). An alloy is a combination of two or more metals or a metal and a non-metal. The metal solder alloy may diffuse into the parts being joined forming an alloy with the parent metal parts. The solder can also mechanically bond to the rough metal surface increasing the joint strength. Clean metal surfaces and a flux to reduce oxides are required.

Solder flows towards the hottest area of the part being heated. Capillary action draws the solder into the narrow spaces between parts.

Soft solder is a tin-lead alloy. Other solder alloys include: tin-antimony, tin-silver, copper-silver and other metal elements. The elements being alloyed control the solder's melting temperature.

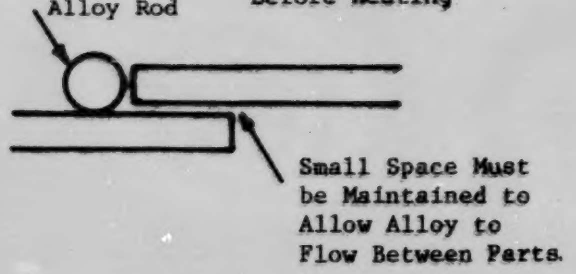


BRAZING

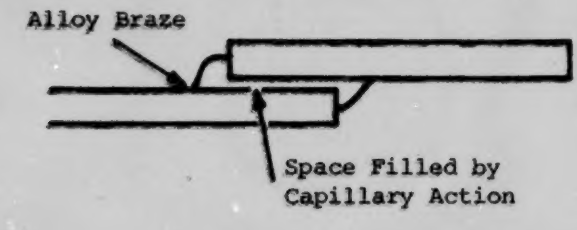
Brazing is the process of joining metals by using a molten non-ferrous metal alloy which melts above 427°C (800°F) to wet the surface of the parts to be joined and allows the metal to solidify. The metal surfaces must be clean and oxide free for the alloy to wet the surfaces. The metals to be joined must be clean and protected with a flux coating when heated to the brazing temperature of the alloy. Parts joined are heated to a temperature below their melting point. Only the brazing alloy melts.

Copper, iron, steel, brass and aluminum can be brazed. Brazed components can be disassembled by reheating the non-ferrous alloy.

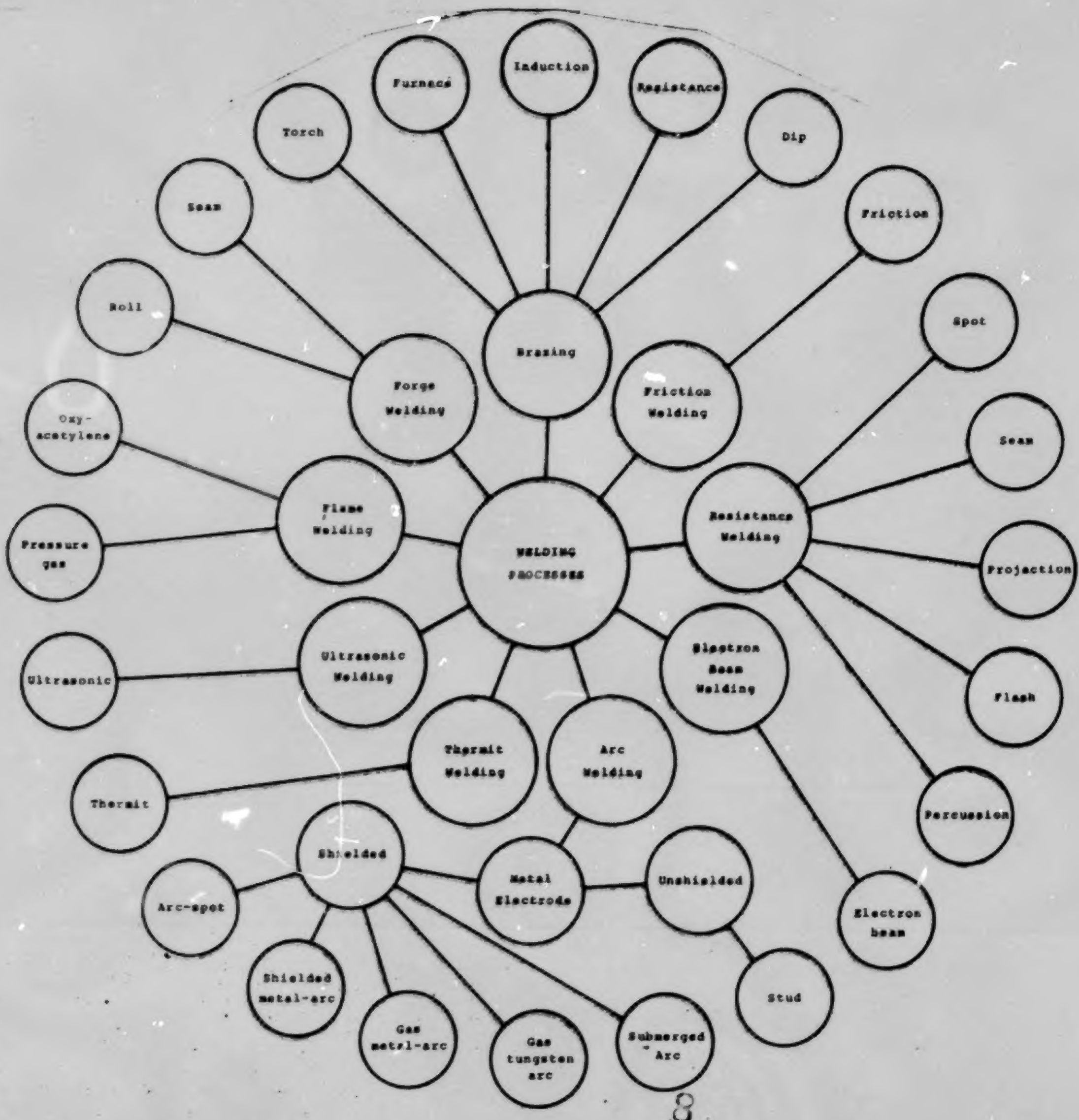
Before Heating


Alloy Rod
Small Space Must be Maintained to Allow Alloy to Flow Between Parts.

After Heating


Alloy Braze
Space Filled by Capillary Action

Welding and brazing methods are identified by the means of heating and pressing the parts together. The diagram below indicates methods commonly used in industry.


Furnace
Induction
Resistance
Torch
Dip
Seam
Friction
Roll
Brazing
Spot
Forge Welding
Friction Welding
Oxy-acetylene
Seam
Flame Welding
Resistance Welding
Pressure gas
WELDING PROCESSES
Projection
Ultrasonic Welding
Electron Beam Welding
Ultrasonic
Flash
Thermit Welding
Arc Welding
Thermit
Percussion
Shielded
Metal Electrode
Unshielded
Arc-spot
Electron beam
Shielded metal-arc
Stud
Gas metal-arc
Gas tungsten arc
Submerged Arc

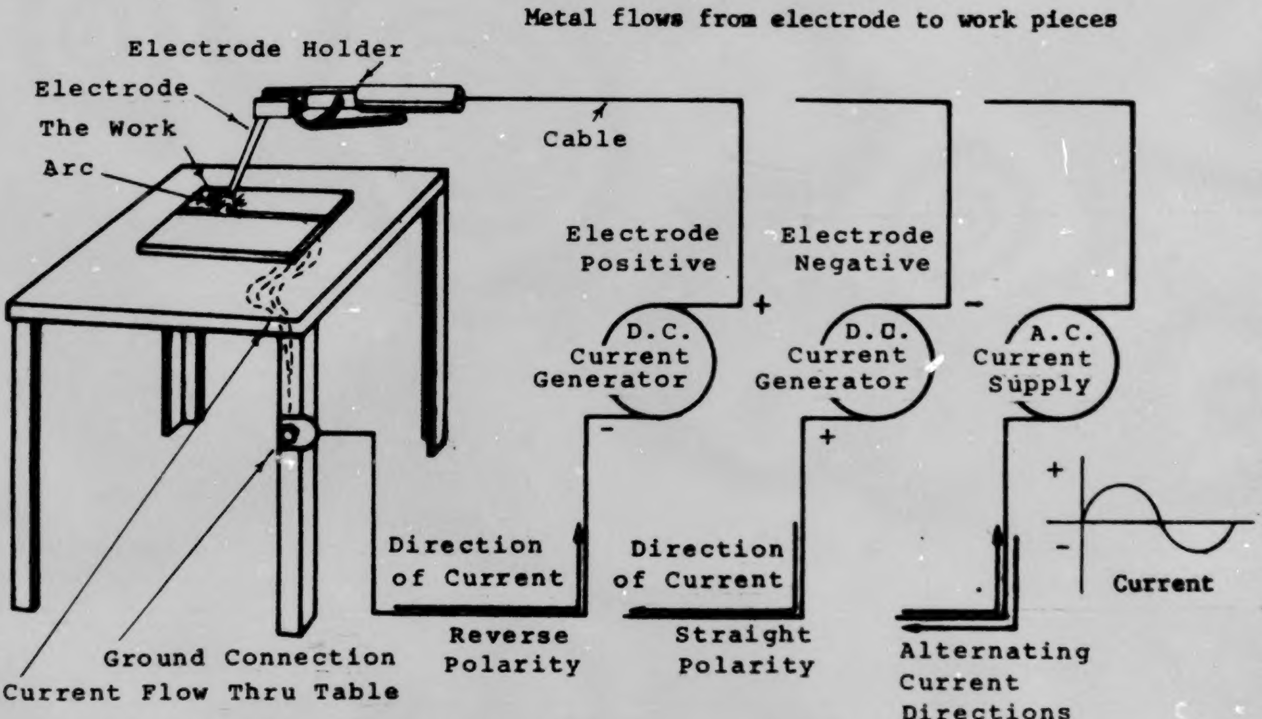
Section 2 - Arc Welding

Arc welding is the process of melting two pieces of metal together using the heat produced in an electric arc which forms between a conducting rod called an electrode and the work piece. In metal electrode welding, the electrode melts and deposits filler metal in the weld joint. Three types of electric arc welding are defined by the way electric current flows through the electrode and electric arc.

A. Straight Polarity - Electrons flow from electrode to work like flow of filler metal. (DC Current)

B. Reverse Polarity - Electrons flow from work to electrode opposite the flow of filler metal. (DC Current)

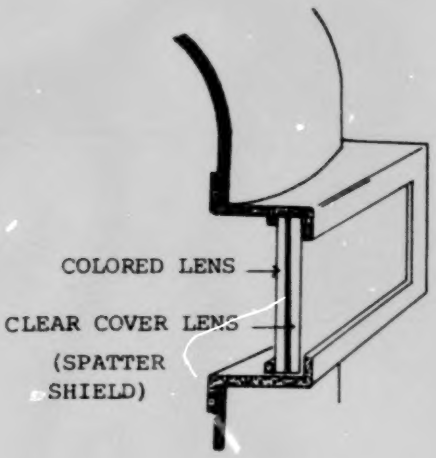
C. Alternating Current - The current flow reverses periodically 120 times per second. (AC Current)

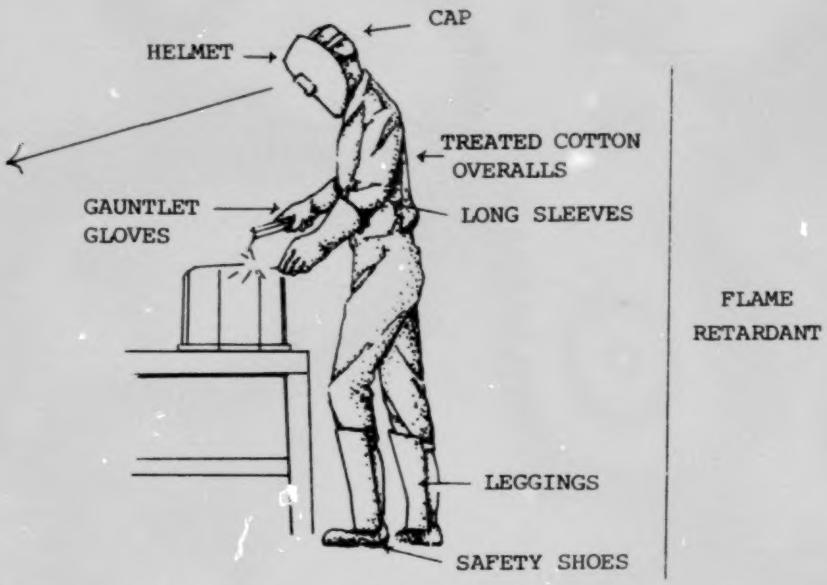

Metal flows from electrode to work pieces
Electrode Holder
Electrode
The Work
Arc
Cable
Electrode Positive
Electrode Negative
+
-
D.C. Current Generator
D.C. Current Generator
A.C. Current Supply
-
+
+
-
Current
Direction of Current
Direction of Current
Reverse Polarity
Straight Polarity
Alternating Current Directions
Ground Connection
Current Flow Thru Table

ELECTRIC ARC WELDING CIRCUITS

SAFETY

Arc welding requires adequate body protection from electric shock, from radiation burns due to the radiation emitted from the arc and from possible molten metal spatter. The bright blue-white light coming from the arc is partially ultraviolet radiation which causes burns like sunburn. The effect is felt too late to correct for poor protection.


COLORED LENS
CLEAR COVER LENS
(SPATTER SHIELD)


CAP
HELMET
TREATED COTTON OVERALLS
GAUNTLET GLOVES
LONG SLEEVES
FLAME RETARDANT
LEGGINGS
SAFETY SHOES

COLORED LENSES ARE MARKED
#10, #11, #12,
#12 BEING THE DARKEST.
USE THE DARKEST LENS POSSIBLE.

Proper Clothing for Arc Welding

NEVER LOOK AT THE WELDING ARC!

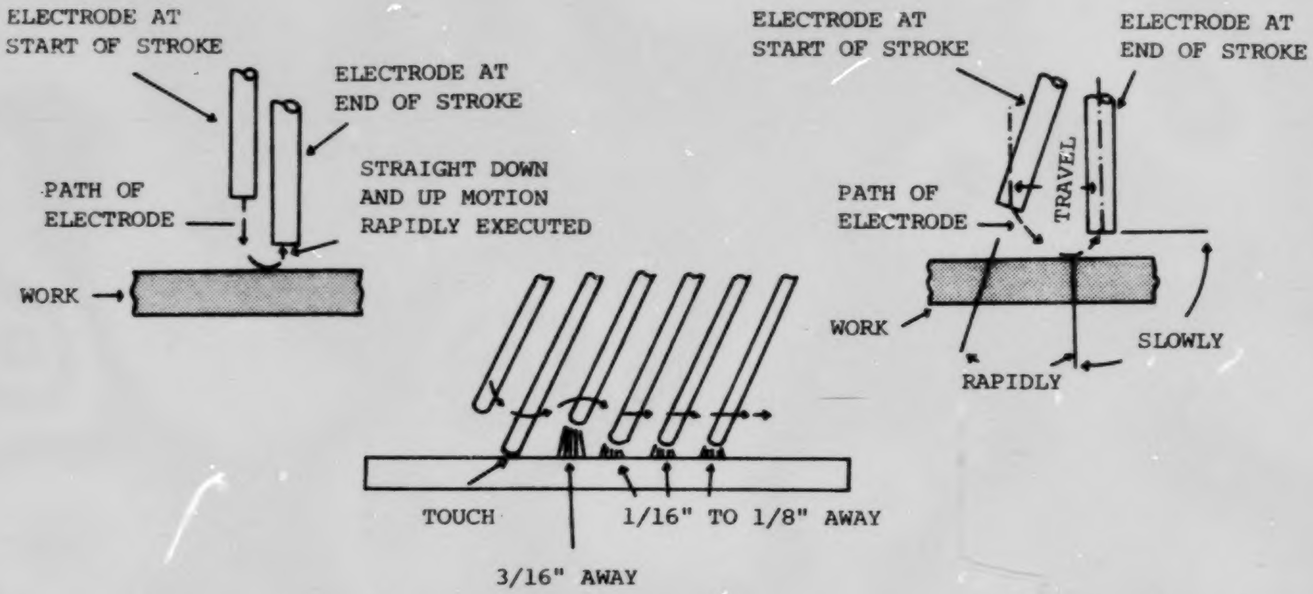
NEVER PICK UP HOT METAL WITH BARE HANDS!

NEVER WELD WITHOUT SKIN PROTECTION!

Eye burns can be caused in seconds. Even the light reflected off objects in the lab can cause burns. Shield your welding area from other workers.

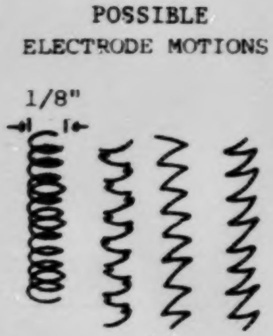
High energy radiation sources such as lasers, welding arcs and X-ray machines all require care in use because of the speed of causing body damage.

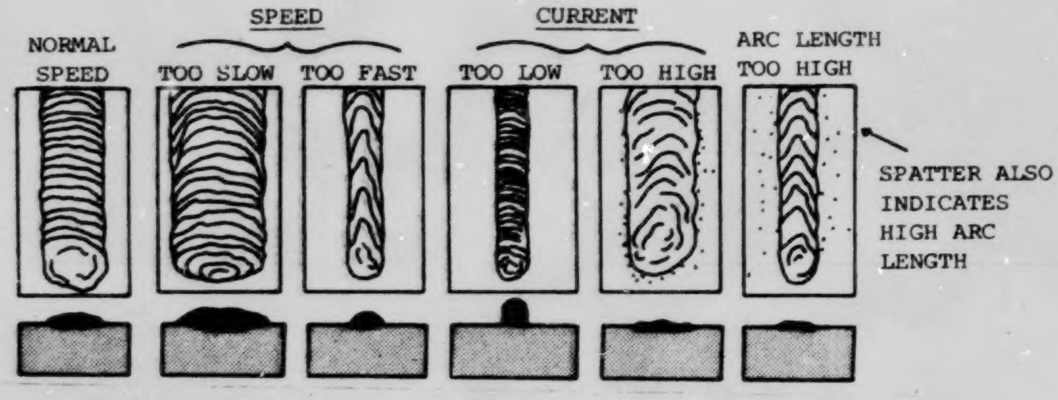
The starting of an electric arc requires skill in positioning the electrode while looking through a very dark lens. Once the arc is started, enough light is generated to see the work. A few methods of starting the arc are shown.


ELECTRODE AT START OF STROKE
ELECTRODE AT END OF STROKE
STRAIGHT DOWN AND UP MOTION RAPIDLY EXECUTED
PATH OF ELECTRODE
WORK
ELECTRODE AT START OF STROKE
ELECTRODE AT END OF STROKE
TRAVEL
PATH OF ELECTRODE
WORK
SLOWLY
RAPIDLY
TOUCH
1/16" TO 1/8" AWAY
3/16" AWAY

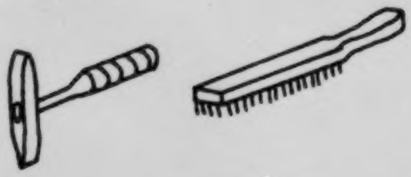
The shape of the molten pool of metal formed at the arc is controlled by the circular motion of the electrode, the length of the arc, the amperage setting and the speed of moving the electrode forward. The stirring motion brings oxides to the surface and makes a more solid weld connection.

The condition of a weld pass is an indication of the quality of a weld

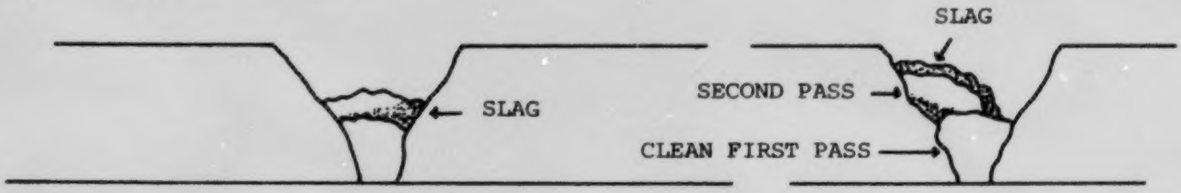

POSSIBLE
ELECTRODE MOTIONS
1/8"


NORMAL SPEED
SPEED
TOO SLOW
TOO FAST
CURRENT
TOO LOW
TOO HIGH
ARC LENGTH TOO HIGH
SPATTER ALSO INDICATES HIGH ARC LENGTH

After making a weld, the slag coating is removed by using a chipping hammer and/or a wire brush.



Safety glasses must be worn under the welding helmet so chipping between weld passes can be safely done. A second weld pass is done on a clean metal surface to prevent pockets of slag from being trapped under the second weld pass.



LABORATORY ACTIVITY AND SKILLS

The student should develop welding skills and knowledge of weld fabrication methods, and of arc welding of steel sheet, angle, and plate made to drawing specifications.

STUDENT PROBLEMS

1. Welding is the process of joining two pieces by ____________________ them together.

2. Arc welding melts the metal by heat from an ______________ ____________.

3. A welding ________________ supplies filler metal to the molten metal pool.

4. Heat is controlled in the weld zone by adjusting the ________________.

5. Arc welding safety requires the wearing of:

    ____

    ____

    ____

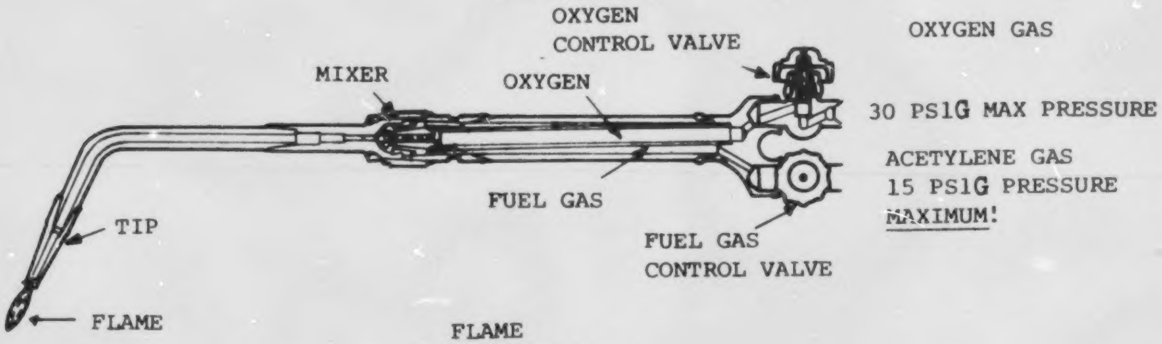
    ____

    ____

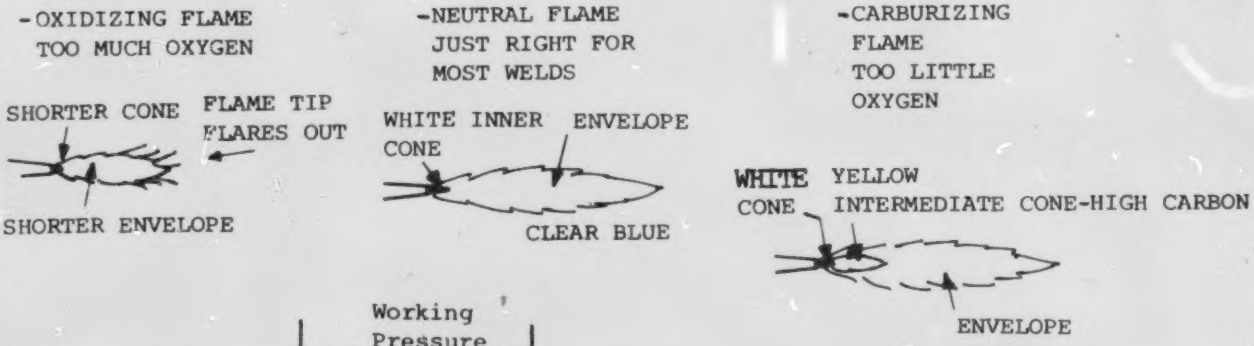
Section 3 - Gas Welding

Gas welding is similar to arc welding except the heat for fusing the pieces together comes from burning a combustible gas with an oxidizing agent. Acetylene gas is burned with oxygen causing the release of heat. The oxygen to acetylene ratio is approximately 2 to 1. The ratio must be carefully controlled so a neutral flame is maintained. An oxygen rich flame oxidizes the metal parts being welded. An excess acetylene flame increases carbon content of the weld metal making it brittle. The welding torch is designed to control flow rate and mix the two gases.

WELDING TORCH

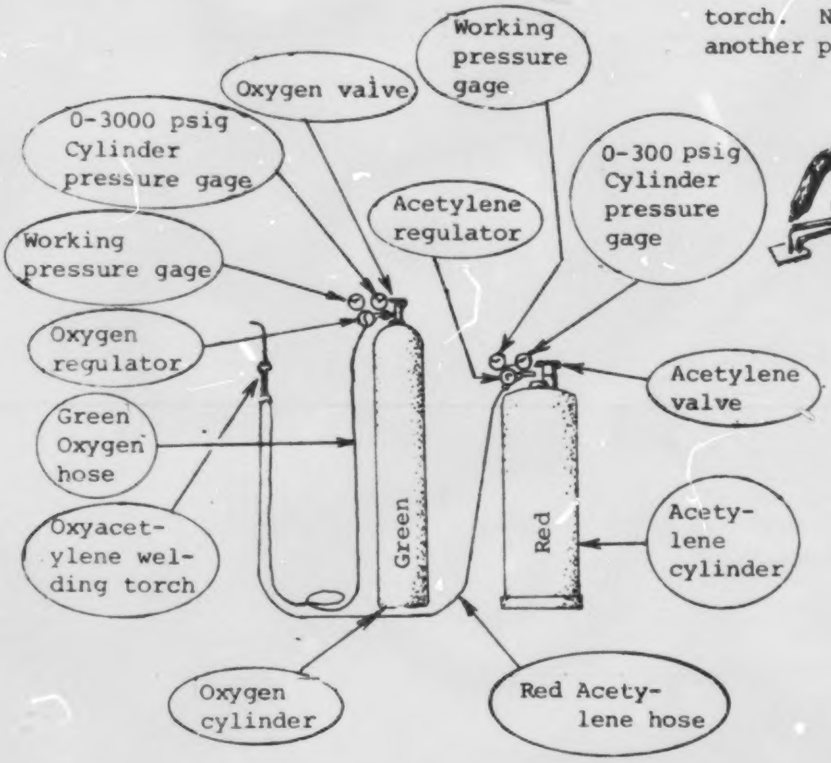

OXYGEN
CONTROL VALVE
OXYGEN GAS
MIXER
OXYGEN
30 PSIG MAX PRESSURE
ACETYLENE GAS
15 PSIG PRESSURE
MAXIMUM!
FUEL GAS
TIP
FUEL GAS
CONTROL VALVE
FLAME

FLAME
ADJUSTMENT

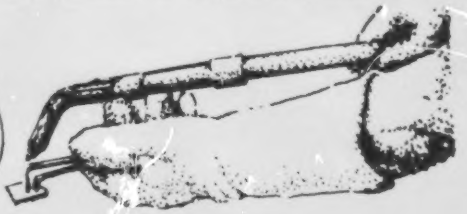

-OXIDIZING FLAME
TOO MUCH OXYGEN
SHORTER CONE
FLAME TIP
FLARES OUT
SHORTER ENVELOPE
-NEUTRAL FLAME
JUST RIGHT FOR
MOST WELDS
WHITE INNER
CONE
ENVELOPE
CLEAR BLUE
-CARBURIZING
FLAME
TOO LITTLE
OXYGEN
WHITE
CONE
YELLOW
INTERMEDIATE CONE-HIGH CARBON
ENVELOPE

Tip Size No.	Working Pressure PSI Oxygen	Working Pressure PSI Acetylene	Metal Thickness, Inches	Filler Rod Dial Inches
1	1	1		
2	2	2	1/32 (22 gage)	1/16
3	3	3	1/16 (16 gage)	1/16
4	4	4	3/32 (13 gage)	1/16, 3/32, or 1/8
5	5	5	1/8 (11 gage)	1/32 or 1/18
6	6	6	3/16	1/8
7	7	7	1/4	3/16
8	8	8	5/16	3/16
9	9	9	3/8	3/16
10	10	10	7/16	3/16 or 1/4

The gas supply to the welding torch is normally from high pressure storage cylinders. The gas pressure is reduced through regulators to about 10 **psig** and supplies the torch through hoses. The complete outfit is shown.

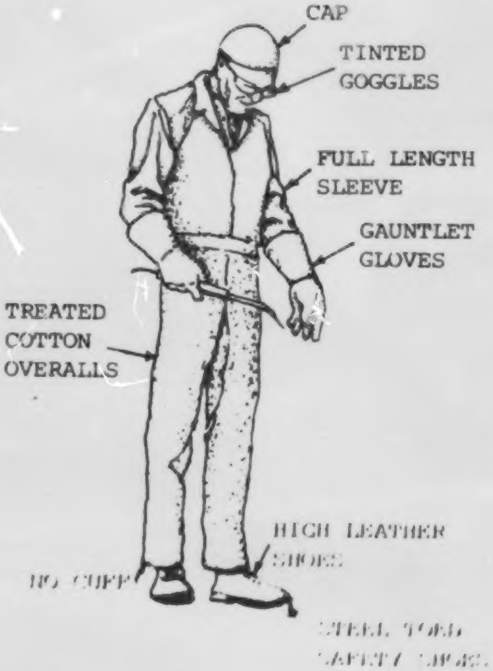

Working pressure gage
Oxygen valve
0-3000 psig Cylinder pressure gage
Acetylene regulator
0-300 psig Cylinder pressure gage
Working pressure gage
Oxygen regulator
Acetylene valve
Green Oxygen hose
Oxyacetylene welding torch
Green
Red
Acetylene cylinder
Oxygen cylinder
Red Acetylene hose

Use the friction lighter to light a torch. Never light it with a match or another person's lighted torch.



SAFETY DRESS AND PRACTICE

1. Never use any oil or grease on or around a welding outfit. Grease or oil can cause a fire when it comes in contact with oxygen.
2. Always use a spark lighter to light the torch, but never matches.
3. Never try to light the torch with both valves open.
4. Always wear goggles when welding.
5. Never allow anyone to watch while you are welding.
6. Always hang the torches in the correct place. Never lay them on the welding table.
7. Always turn off the torch when you have completed a weld.
8. Test for hose leaks with soapsuds.
9. Never weld on containers with small openings. Gases can collect and cause an explosion.

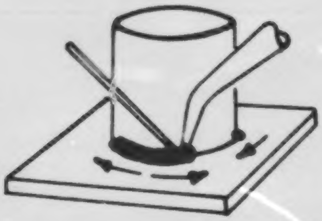

CAP
TINTED GOGGLES
FULL LENGTH SLEEVE
GAUNTLET GLOVES
TREATED COTTON OVERALLS
HIGH LEATHER SHOES
NO CUFF
STEEL TOED SAFETY SHOES

KEEP A FIRE EXTINGUISHER NEAR WELD AREA.

GAS WELD PROCEDURE

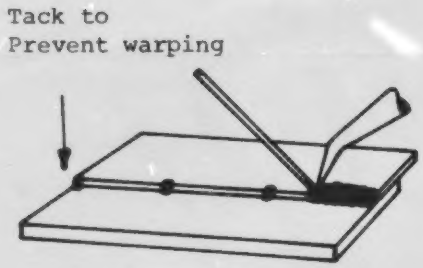
Gas welding requires the melting of the metal parts to fuse them together and the adding of filler metal. The torch flame tip white inner cone must just touch the molten metal pool. Rotating the torch tip in an arc stirs the molten metal removing impurities. The best weld position is horizontal, where the molten metal pool is easy to control.

TYPES OF WELDS

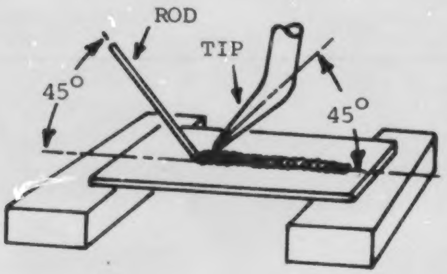


Tube to

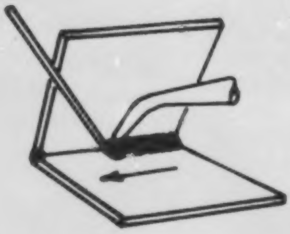
plate weld


Tack to
Prevent warping

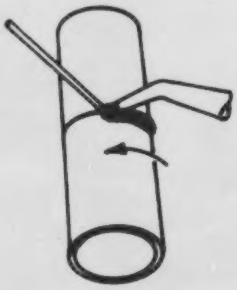
lap weld


ROD
TIP
45°
45°

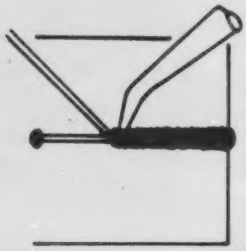
butt weld



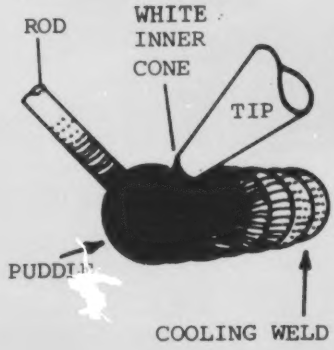
fillet weld



tube butt weld



butt weld


ROD
WHITE
INNER
CONE
TIP
PUDDLE
COOLING WELD

Move the puddle gradually

forward, and add metal.

LABORATORY ACTIVITIES AND SKILLS

Oxygen acetylene welding of sheet steel, tubing and angle iron as specified on drawings will develop skills and knowledge of weld fabrication methods.

STUDENT PROBLEMS

1. Welding temperature is obtained in gas welding by burning____________ with ____________________ gas.

2. The gas welding flame must be adjusted to produce a neutral flame so the weld made will not be ________________________.

3. The heat available for melting the metal is controlled by the ___________________ of acetylene gas to the torch tip.

4. The working pressures for gas welding 16 gage steel sheet are

   ___________________ for oxygen

   ___________________ for acetylene

5. The welding torch tip size for 16 gage steel is ____________________.

6. Proper gas welding apparel includes:

   ____

   ____

   ____

   ____

7. Gas welding is best done with work to be welded in a _______________ position.

8. In gas welding the impurities are removed by stirring the molten metal pool with the ___________________ jet from the torch tip.

9. Name four common welds made.

   ____

   ____

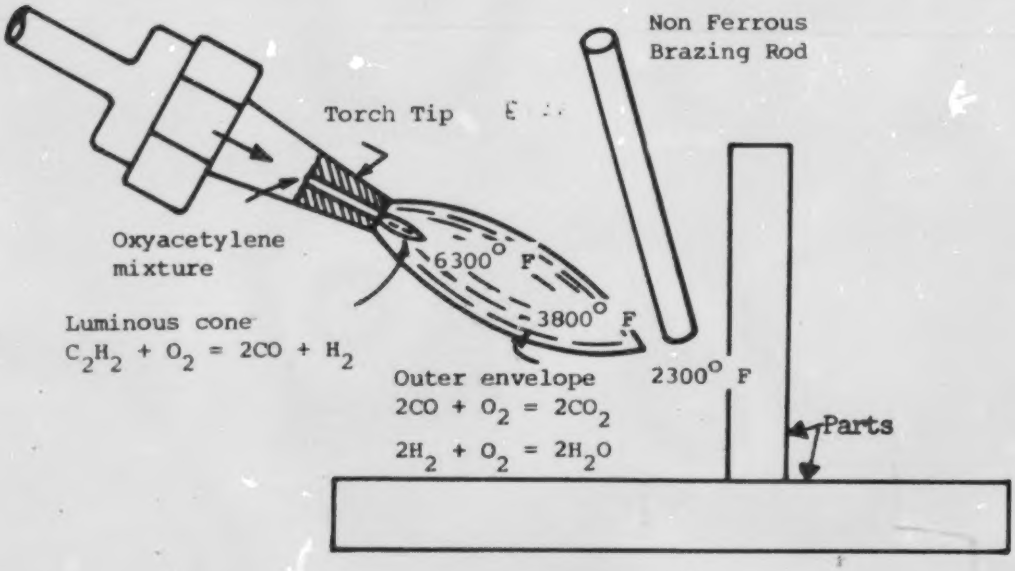
   ____

   ____

Section 4 - Brazing

Brazing is similar to gas welding except the parts to be assembled are heated to the melting temperature of the non-ferrous filler alloy. Parts must be clean of oxide and must be fluxed before heating to prevent oxidation.

Parts to be brazed should not be over heated. The welding torch tip should be held farther away from the work pieces. The molten brazing alloy will flow toward the hottest spot on the metal pieces.


Non Ferrous Brazing Rod
Torch Tip
Oxyacetylene mixture
6300° F
3800° F
Luminous cone
$C_2H_2 + O_2 = 2CO + H_2$
Outer envelope
$2CO + O_2 = 2CO_2$
$2H_2 + O_2 = 2H_2O$
2300° F
Parts

LABORATORY ACTIVITY AND SKILLS

The student should experience brazing steel, cast iron, and copper alloys. A tensile test should be made on one of the connections to determine load required for failure and calculated stress for failure. Importance of clean surfaces should be stressed. Furnace brazing and oxygen acetylene torch brazing should be discussed and/or demonstrated.

STUDENT PROBLEMS

1. Brazing joins metals together with a non-ferrous alloy which melts above _______________.

2. Lower temperature must be used to braze joints because of the _______________ temperature of the alloy brazing rod.

3. Molten brazing alloy flows towards the _____________________ _________________ of the metal pieces.

4. _________________ forms a coating over the clean metal surface to remove impurities and reduce oxidation.

5. Metal parts must be _______________ so the molten brazing alloy wets the metal surface for a strong bond.

6. Select a brazing rod to connect two pieces of cast iron. _____________________

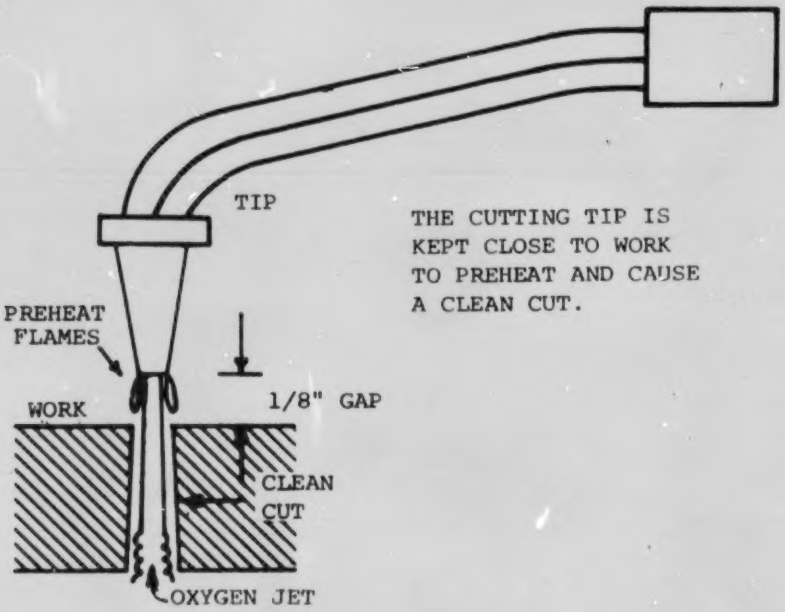
7. An oxygen rich torch flame should not be used because it _______________ the metal surface.

Section 5 - Oxygen-Acetylene Torch Cutting

Oxygen-acetylene torch cutting is a process which uses a jet of oxygen to oxidize heated steel to iron oxide and blow the molten material from the cut being made. Steel must be heated to near red hot before the cutting starts. The cutting torch has preheat flames to do the heating. Once the metal is hot, an oxygen valve is opened allowing an oxygen jet to start cutting. The oxidized steel produces heat which continues the reaction. The cutting torch is used on an oxygen-acetylene welding set having gas tanks, regulators, and hose. The oxygen supply pressure to the torch is set at the proper value for the particular cutting tip and metal thickness to be cut.

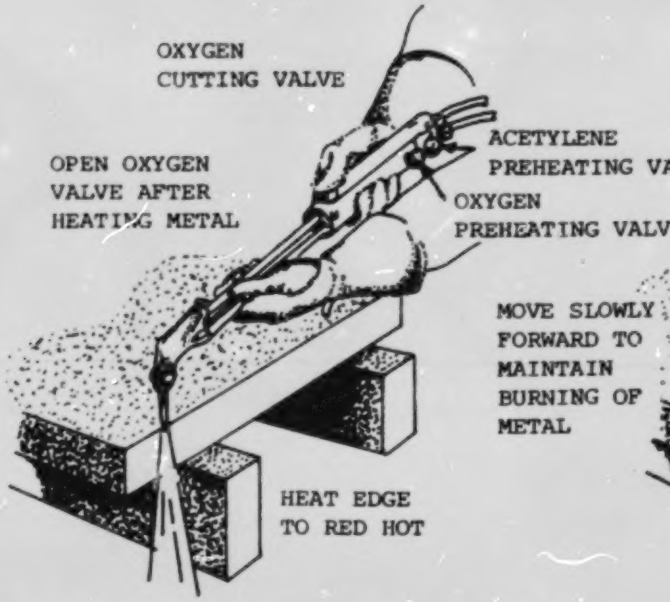
GAS PRESSURE FOR CUTTING TORCHES

Tip No.	Thickness of Metal Inches	Oxygen Pressure PSI	Acetylene Pressure PSI	Acetylene Consumption Cubic Feet per Hour	Oxygen Consumption Cubic Feet per Hour
L-00	1/8	10	5	9.5	35
L-0	1/4	15	5	9.5	40
L-1	3/8	20	5	9.5	45
L-2	1/2	25	5	9.5	50
L-2	3/4	30	7	15.3	60
L-2	1	40	7	15.3	100
L-2	1-1/2	50	8	15.3	150
L-2	2	60	8	15.3	200
L-3	3	70	10	25.2	275
L-3	4	80	10	25.2	350
L-3	5	90	10	25.2	425
L-4	6	100	12	27.3	550
L-5	8	100	12	27.3	825
L-6	10	100	14	28.2	1000

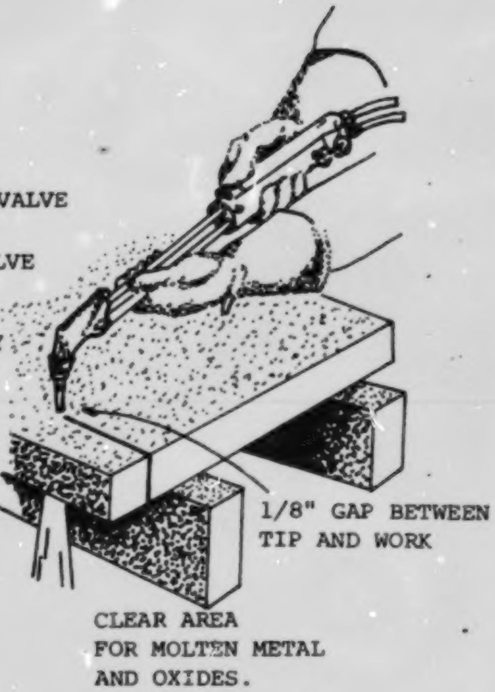


THE CUTTING TIP IS KEPT CLOSE TO WORK TO PREHEAT AND CAUSE A CLEAN CUT.

STARTING THE CUT


OXYGEN CUTTING VALVE
ACETYLENE PREHEATING VALVE
OPEN OXYGEN VALVE AFTER HEATING METAL
OXYGEN PREHEATING VALVE
HEAT EDGE TO RED HOT

CONTINUING THE CUT


MOVE SLOWLY FORWARD TO MAINTAIN BURNING OF METAL
1/8" GAP BETWEEN TIP AND WORK
CLEAR AREA FOR MOLTEN METAL AND OXIDES.

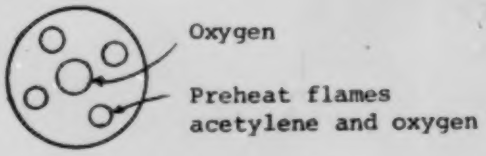
SAFETY

Wear protection like the gas welder; gloves, apron, safety shoes, cap and cuffless pants. Never cut on tank with small openings.

Never cut objects which contain flammable materials. Oxygen can react with vapors causing an explosion!

Cutting tips are designed with four to eight preheat flames around the oxygen jet. Tips must be clean to give smooth straight cuts.

End View-Torch Tip


Oxygen
Preheat flames acetylene and oxygen

LABORATORY ACTIVITY AND SKILLS

Each student should practice cutting steel with an oxygen acetylene torch. He/she should know the importance of clean torch tip, proper oxygen pressure, clean metal surface, and steady torch movement. SAFETY - DO NOT CUT ON TANKS OR CLOSED VESSELS!

STUDENT PROBLEMS

1. A ½ inch thick steel plate is to be cut with an oxygen-acetylene cutting torch.

    What tip size is proper? ________________

    What oxygen pressure should be used? __________________

    What acetylene pressure should be used? ____________________

2. How far from the work should the torch tip be held? ____________________

Section 6 - Silver Soldering

Silver soldering uses a hard solder with a higher melting point than the soft lead-tin solders. Silver soldering requires temperatures above 800°F and can be considered a brazing process.

Silver solder is typically used where greater strength and higher operating temperatures are needed. Clean surfaces and fluxes are required. Boric acid makes a good flux.

Commonly Used Brazing Metals and their Uses

Braze Metal	Composition		Brazing Process	Base Metals
Brazing brass	60% Cu, 40% Zn		Torch Furnace Dip Flow	Steel, copper, high copper alloys, nickel alloys, stainless steel
Manganese bronze	58.5% Cu, 1%Sn, 1%Fe, o.25%Mn, 39.5% Zn		Torch	Same as above
Nickel silver	18% Ni, 55-65% Cu, 27-17% Zn		Torch Induction	Steel, nickel, nickel alloys
Copper silicon alloys	1.5% Si, 0.25% Mn, 98.25% Cu, 1.5%Si, 1.00% Zn Zn, 97.5% Cu		Torch	Steel
Silver alloys (no phosphorus)	20%Ag, 5% P, 80% Cu	Silver Solders	Torch Furnace Induction Resistance Dip	Copper, copper alloys
Silver alloys (with phosphorus)	15%Ag, 5% P 80% Cu		Torch Furnace Induction Resistance Dip	Copper, copper alloys
Copper phosphorus	93%Cu, 7% P		Torch Furnace Induction Resistance Dip	Copper, copper alloys

LABORATORY ACTIVITY AND SKILLS

Silver and sil floss soldering of components with oxygen-acetylene torches should be done by each student. Low melting temperature, and clean fluxed surfaces should be stressed.

CHAPTER II

PLASTICS FABRICATION

Section 1 - Types, Properties and Identification

Plastics are hydrocarbon compounds which can be classified according to thermal properties. Thermosetting plastics harden on heating while thermoplastics soften on heating. Plastics are any of various non-metallic compounds synthetically produced (usually from organic compounds by polymerization) which can be molded into various forms and hardened for commercial use.

Plastics can be identified by five burning characteristics: ease of lighting, self extinguishing, odor, nature of flame and behavior of material. They can also be identified by mechanical and physical properties, such as tensile strength and chemical resistance. Tables 4 and 5 in the Appendix list characteristics and properties of plastics.

LABORATORY ACTIVITY AND SKILLS

The student should be familiar with the properties of commercially available plastics and should be able to identify unknown samples by their physical properties.

STUDENT PROBLEMS

1. The two general plastic types are ______________________________ and ___________________________.

2. Plastics can be identified by burning characteristics which include five observations. List them.

   ____

   ____

   ____

   ____

   ____

3. Find the tensile strength of nylon 6 from published data.

   ______________________________ PSI.

Section 2 - Safety

Safe plastics fabrication and cementing requires the control of solvent vapors and waste plastic chips and scrap produced. The equipment used for machining plastics is subject to abrasive wear from the plastic powders on the sliding metal surfaces. Since many plastics are flammable, and since heat is generated when they are machined, it is necessary that all flammable materials, including dust and chips, be removed from the area.

General safety practice then requires the following procedures.

1. Flammable solvents must be kept in fireproof containers.

2. Flammable solvents must be used in properly ventilated areas with explosion proof electrical systems, and adequate foam or sprinkler systems to limit propagation of a fire.

3. Adequate dust collection systems must be used to remove toxic and/or flammable particles from the production area.

4. Adequate ventilation systems must be used to guarantee adequate air standards for the worker.

5. Scrap must be removed to make a clean working area with minimal combustible materials.

6. Body contact with solvents which may be detrimental to one's health must be minimized. The properties of any chemical or compound should be studied for proper safety procedures before being used in the lab. Good references include:

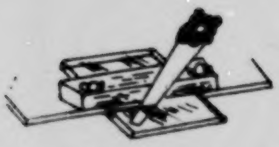
   Manufacturers of material
   Chemical Engineers Handbook
   Chemistry Handbook
   OSHA Standards - Toxicity Level Limits

LABORATORY SKILLS

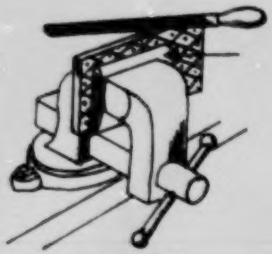
The student should be aware of safety practices when fabricating or machining plastics as well as the flammability and toxicity hazards of solvent and plastic compounds.

Section 3 - Machining, Fasteners, Bonding, Forming and Molding

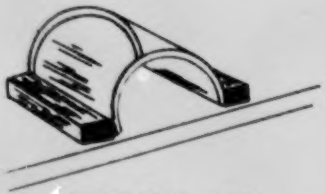
Manufacturers' literature indicates assembly and manufacturing methods which can be used on different plastics. Some methods of fabrication are shown. Table 7 of the Appendix indicates appropriate methods for different plastics.



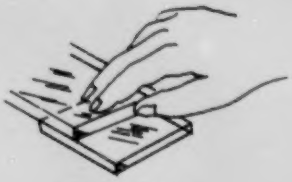
SAWING



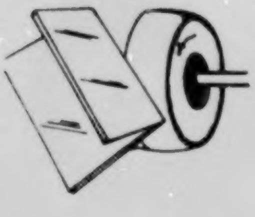
FILING



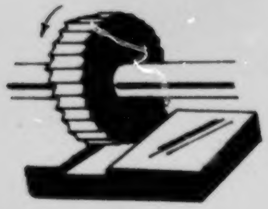
HEATING AND BENDING



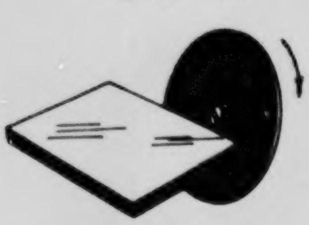
CEMENTING



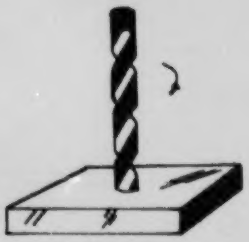
POLISHING



MILLING

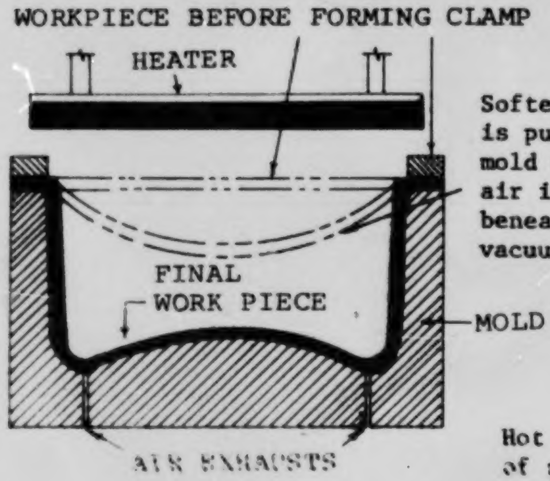


SANDING



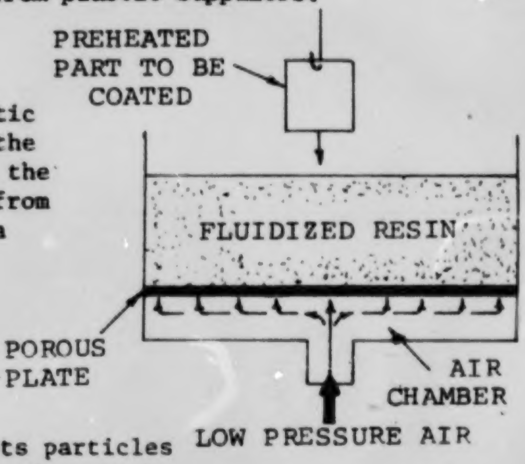
DRILLING

Machining specs are available from plastic suppliers.


WORKPIECE BEFORE FORMING CLAMP
HEATER
FINAL WORK PIECE
MOLD
AIR EXHAUSTS

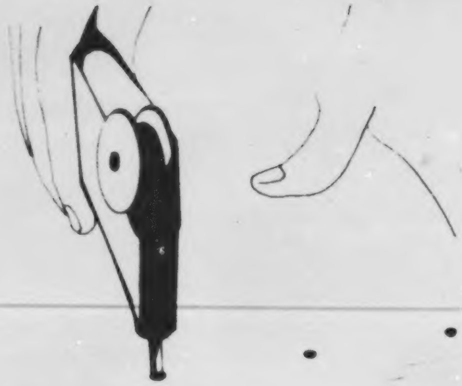
Softened plastic is pushed to the mold shape as the air is drawn from beneath with a vacuum pump.

VACUUM FORMING

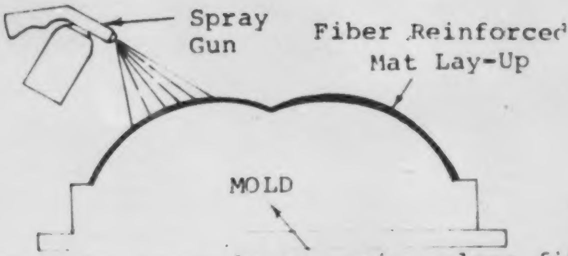

PREHEATED PART TO BE COATED
FLUIDIZED RESIN
POROUS PLATE
AIR CHAMBER
LOW PRESSURE AIR

Hot part melts particles of plastic powder which coat the parts.

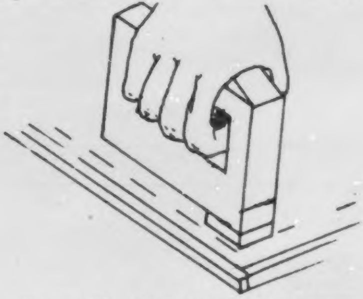
PLASTIC COATING PARTS



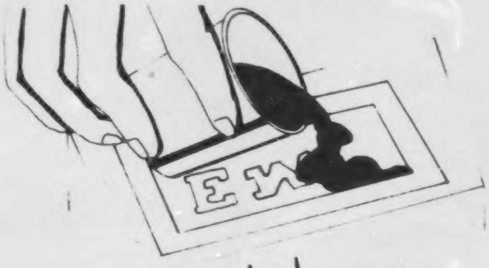
A rivet gun being used to insert rivets for sheet fabrication.


Spray Gun
Fiber Reinforced Mat Lay-Up
MOLD

Polyester spray lay-up using glass fiber reinforcing mat.

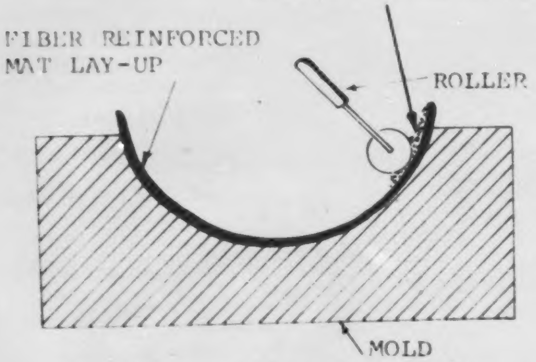


Liquid plastic resin with hardener is cast in a mold.

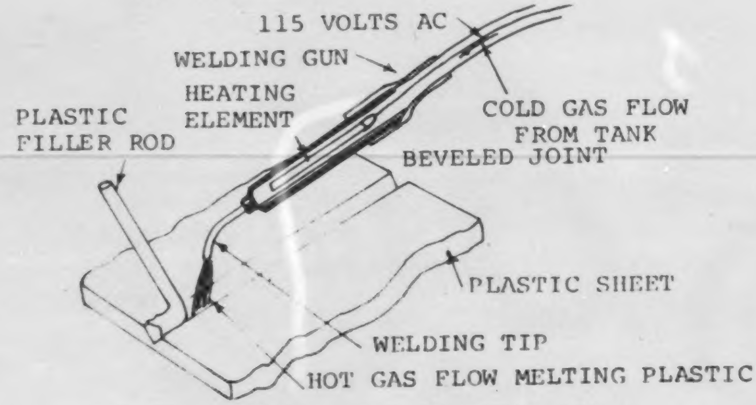


Casting

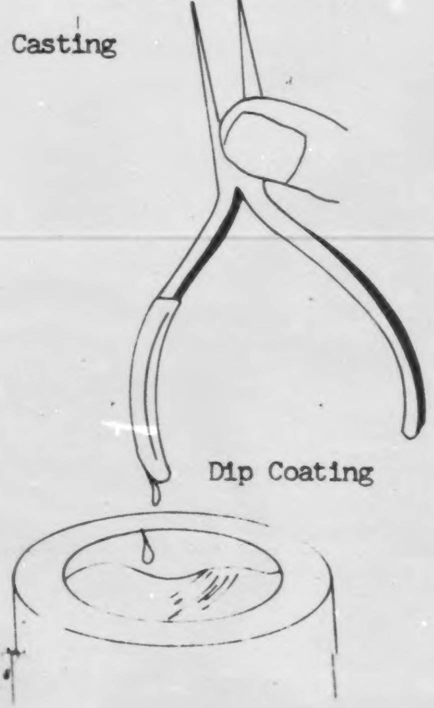
Liquid plastic resin with hardener is rolled into mat.


FIBER REINFORCED MAT LAY-UP
ROLLER
MOLD

Roller spreads and smooths the resin.


115 VOLTS AC
WELDING GUN
HEATING ELEMENT
PLASTIC FILLER ROD
COLD GAS FLOW FROM TANK
BEVELED JOINT
PLASTIC SHEET
WELDING TIP
HOT GAS FLOW MELTING PLASTIC

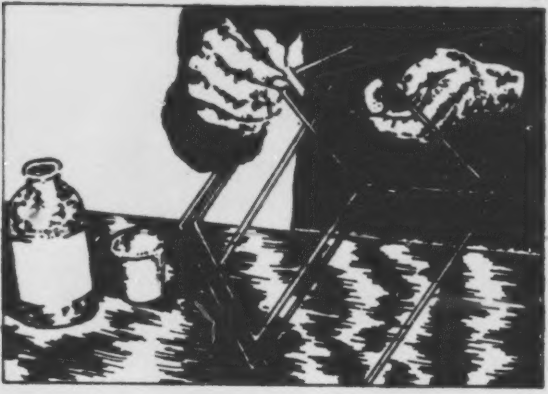
Hot gas welding. Gas flows through the tubing from the tank, around an electrical wire heating element, and out the tip. Gas, which is invisible, is shown in the drawing melting the plastic to make a weld.

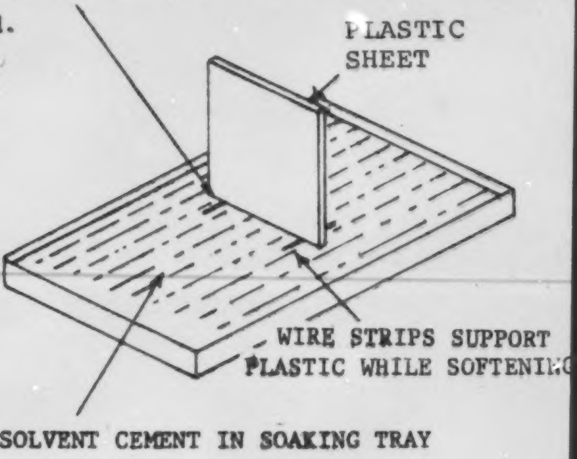


Dip Coating

Solvent Bonding of Plastic

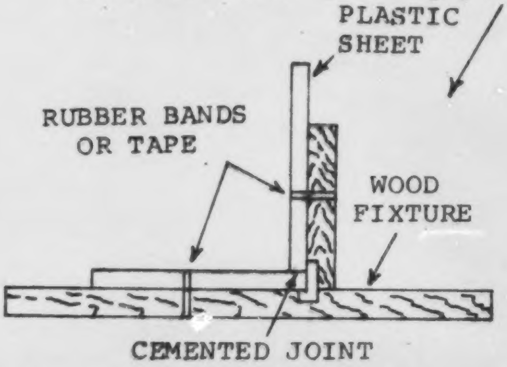
Solvent cement softens the edge of the plastic which is pressed against another piece to make a bond.





Capillary action draws the solvent cement into joint when applied with a brush. A light pressure holds the joint secure.

Soaking plastic in solvent cement before joining parts.



A fixture to hold plastic sheet while the joint cures.

SOLVENTS FOR CEMENTING PLASTICS

	TYPE OF PLASTIC	CLEANING SOLVENT RECOMMENDED (A)	SOLVENT RECOMMENDED IF SOLVENT-BONDABLE
THERMOPLASTIC PLASTICS	Acetal	Methyl ethyl ketone (MEK) or acetone	
	Acrylic	Methyl alcohol or isopropyl alcohol	Methyl ethyl ketone (MEK) or methylene chloride
	Acrylonitrile-butadiene-styrene (ABS)	Methyl alcohol or isopropyl alcohol	
	Cellulose acetate	Methyl alcohol or isopropyl alcohol	MEK or methyl alcohol
	Cellulose acetate butyrate	Methyl alcohol or isopropyl alcohol	MEK or methyl alcohol
	Cellulose nitrate	Methyl alcohol or isopropyl alcohol	MEK or methyl alcohol
	Ethyl cellulose	Methyl alcohol or isopropyl alcohol	1:1 blend of ethyl acetate and methyl alcohol
	Nylon	MEK or acetone	
	Polycarbonate	Methyl alcohol or isopropyl alcohol	Methylene chloride
	Polyethylene (C)	MEK or acetone	
	Polypropylene	MEK or acetone	
	Polystyrene	Methyl alcohol or isopropyl alcohol	Toluene or xylene
	Polyvinylchloride	MEK or acetone	Tetrahydrofuran
	Tetrafluoroethylene (D)	MEK or acetone	
THERMOSETTING PLASTICS	Diallylphthalate	MEK or acetone	
	Epoxy	MEK or acetone	
	Melamine	MEK or acetone	
	Phenolic	MEK or acetone	
	Polyester	MEK or acetone	
	Polyethylene terephthalate (C)	MEK or acetone	
	Polyurethane	MEK or acetone	
	Urea	MEK or acetone	

SEE TABLE 2 IN THE APPENDIX

LABORATORY ACTIVITY AND SKILLS

The student should have lab projects which require sawing, bending, cementing, polishing, and drilling of plastic components. Examples of vacuum forming and coatings should be studied.

STUDENT PROBLEMS

1. Name the assembly methods for nylon.

    ____

    ____

    ____

    ____

    ____

2. Name three ways to produce a curved surface with plastics.

    ____

    ____

    ____

3. A jet of high temperature gas to weld together thermoplastic is called ____________________________ welding.

4. Acrylic can be solvent cemented using ______________________ as the solvent.

5. Find an adhesive type to bond nylon to metal.

    ____

    ____

6. Find an adhesive type to bond glass to cellulose acetate.

    ____

7. Determine the sawing speed to cut acrylic plastic sheet.

    ____

8. Name the burning characteristics of nylon. (To answer, use published data on plastics.)

    ____

    ____

    ____

    ____

    ____

9. Determine the drilling speed, in surface feet per minute, for polycarbonates.

    ____

CHAPTER III

TUBING AND PIPING FABRICATION

Section 1 - Introduction

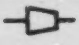
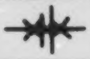
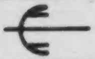
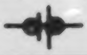
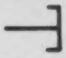
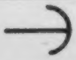
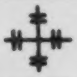
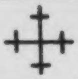
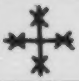
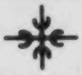
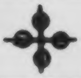
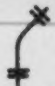
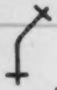
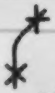
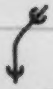
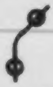
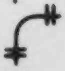
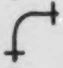
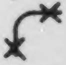
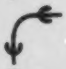
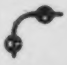
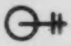
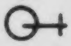
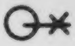
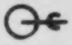
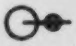
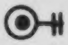
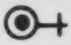
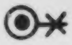
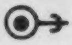
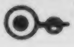
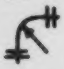
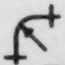
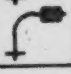
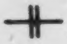
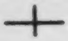
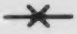
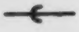
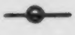
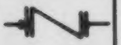
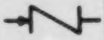
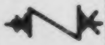
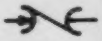
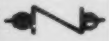
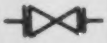
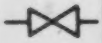
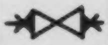
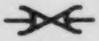
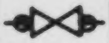
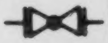
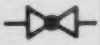
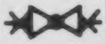
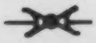
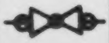
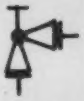
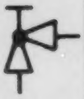
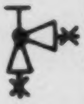
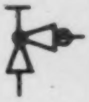
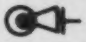
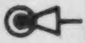
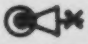
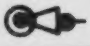
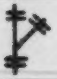
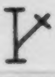
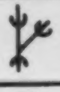
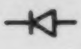
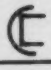
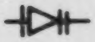
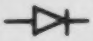
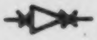
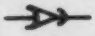
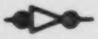
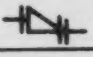
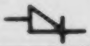
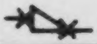
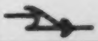
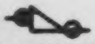
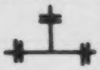
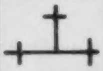
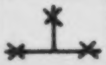
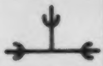
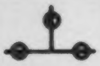
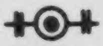
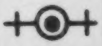
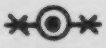
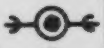
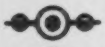
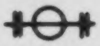
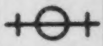
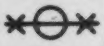
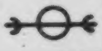
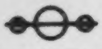
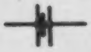
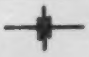
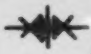
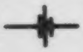
Liquid and gaseous fluids, both compressible and incompressible are stored or transferred through pipe or tubing. Pipe is fabricated with a set of tolerances which are dimensionally not as tight as those on tubing.

Tubing is made in a large range of sizes and is cold rolled or drawn to tight dimensional tolerances.

Pipe and tubing are made of steel, wrought iron, cast iron, stainless steel, seamless brass, copper, aluminum, glass and plastic.

Section 2 - Symbols and Schematics

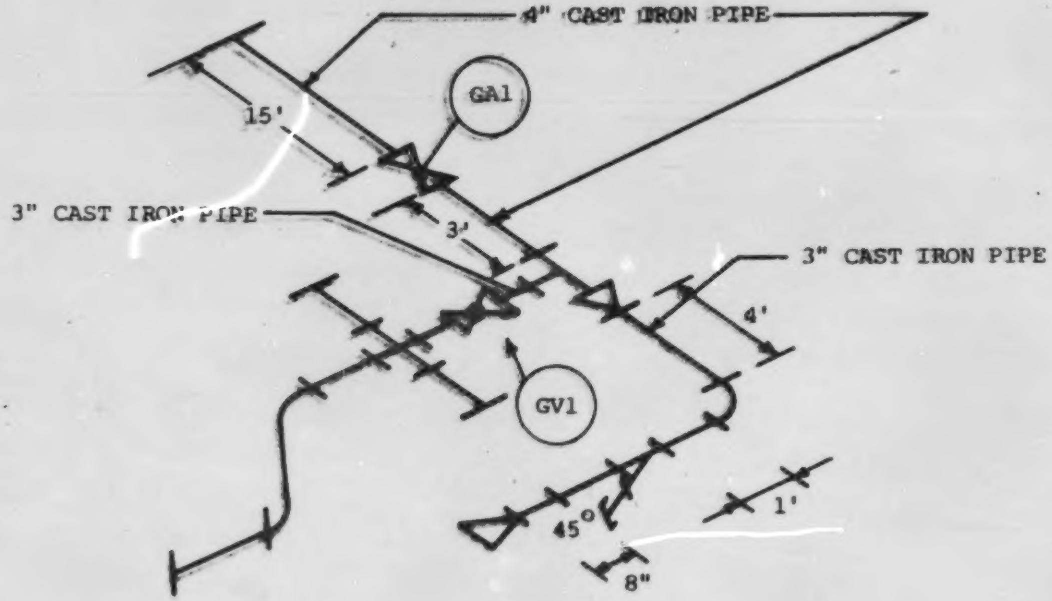
Pipe systems which control fluid flow paths are designated by single line drawings. The piping is designated by a line and the fittings and valves are designated by standard American National Standards Institute (ANSI) symbols.

FITTING	FLANGED	SCREWED	WELDED	BELL AND SPIGOT	SOLDERED
BUSHING					
CAP					
CROSS STRAIGHT SIZE					
ELBOW 45 DEGREE					
90 DEGREE					
TURNED DOWN					
TURNED UP					
LONG RADIUS					
STREET					
JOINT (COUPLING) CONNECTING PIPE					
VALVES CHECK STRAIGHTWAY					
GATE					
GLOBE					
ANGLE GLOBE ELEVATION					
GLOBE PLAN					
LATERAL					
PLUG PIPE PLUG					
REDUCER CONCENTRIC					
ECCENTRIC					
TEE STRAIGHT					
OUTLET UP					
OUTLET DOWN					
UNION					

Hydraulic and pneumatic (air) control symbols are specified by the American Standards Association. A good reference is "Lightning Reference Handbook," Third Edition, 1973, Paul-Munroe Hydraulics, Inc., California.

Piping system drawings for shop or field fabrication are isometric drawings with specifications called out on a bill of materials.

PIPING ISOMETRIC DRAWING

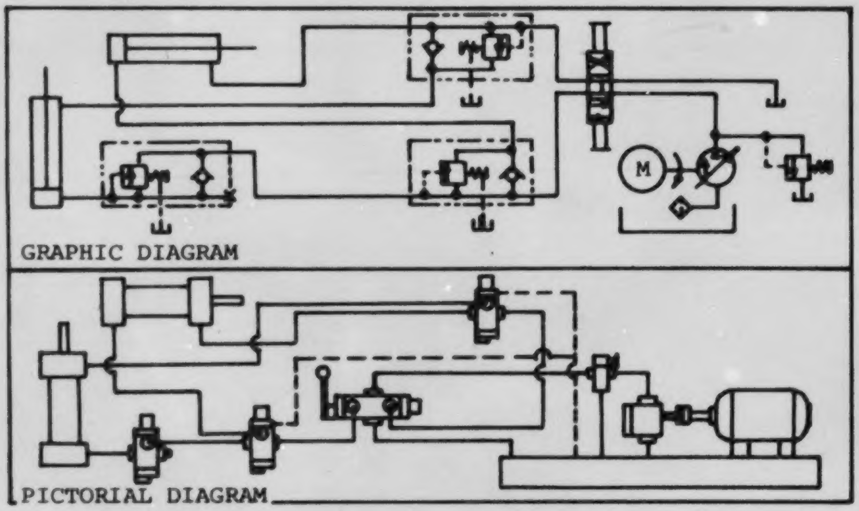

4" CAST IRON PIPE
GA1
15'
3" CAST IRON PIPE
3'
3" CAST IRON PIPE
4'
GV1
45°
1'
8"

Bill of Materials

Symbol	Qty	Item	Company Standard or Spec.
GA1	1	150-#4" Gate Valve	
GV1	1	150-#3" Globe Valve	Jenkins Iron Body Globe - 250 PSI at 450° F.

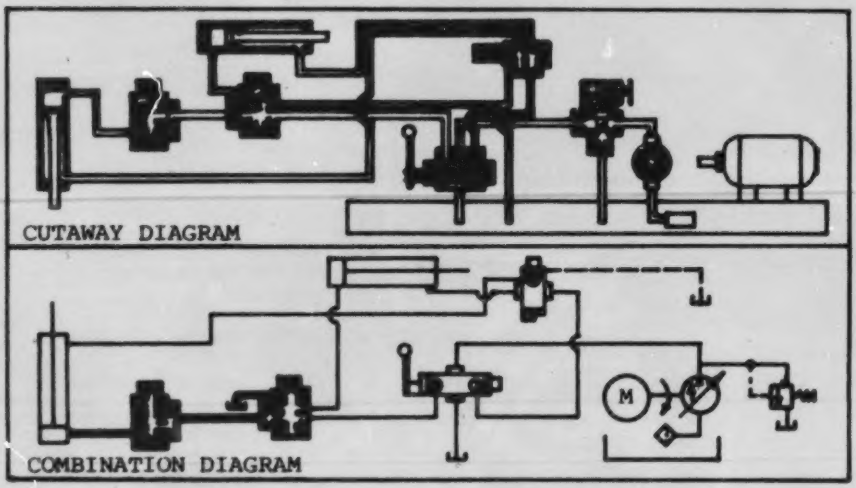
Schematic piping drawings are used for specifying control diagrams.

Controls on Two Hydraulic Cylinders


M
GRAPHIC DIAGRAM
PICTORIAL DIAGRAM

American Standards
Graphic Symbols

Component
Diagram


CUTAWAY DIAGRAM
M
COMBINATION DIAGRAM

Component Diagram
with Component
Intervals Shown

Combination of
Diagram Formats.

LABORATORY SKILLS

The student should be able to draw a schematic with correct ANSI symbols. The student should be able to identify components indicated on a schematic.

STUDENT PROBLEMS

1. Identify each of the symbols shown on the schematic below. Use each symbol type only once. (Seven answers)

______________________ ______________________

______________________ ______________________

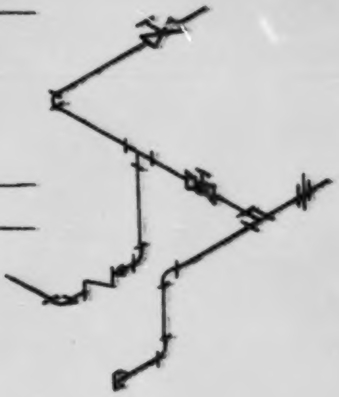
______________________ ______________________

____

2. Identify four piping system connection methods.

______________________ ______________________

______________________ ______________________



Section 3 - Components

Piping systems are made of pipe, tube, or hose sections and the components they connect together.

Standards have developed from many industries and professional organizations.

Standards for tubing include those from: (ASTM), (ASME), (SAE), (ASA).

Standards for pipe include those from: (ASTM), (ASME), (SAE), (API).

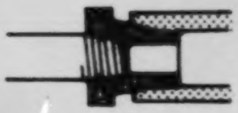
Standards for hoses include those from: (ASTM), (SAE), (ASA).

(ASA)	American Standards Association
(ASTM)	American Society of Testing Materials
(ASME)	American Society of Mechanical Engineers
(SAE)	Society of Automotive Engineers
(API)	American Petroleum Institute

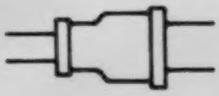
Pipe joints and fittings are used to join pipes together to change size or direction, or to allow for branching. The joints and fittings may be screwed, welded, flanged, soldered or clamped.

Pipe joints and fittings are used to join pipes together to change size or direction or to allow for branching. The type of joint and fittings may be screwed, welded, flanged, soldered or clamped.

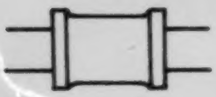
SCREWED PIPE FITTINGS



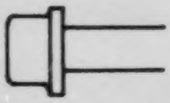
A REDUCING BUSHING IS USED TO GO FROM ONE PIPE SIZE TO ANOTHER.



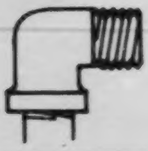
A REDUCING COUPLING ALSO IS USED TO CHANGE PIPE SIZE, BUT HAS BOTH FEMALE THREADS.



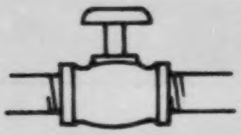
A STRAIGHT COUPLING JOINS TWO PIPE SECTIONS THE SAME SIZE.



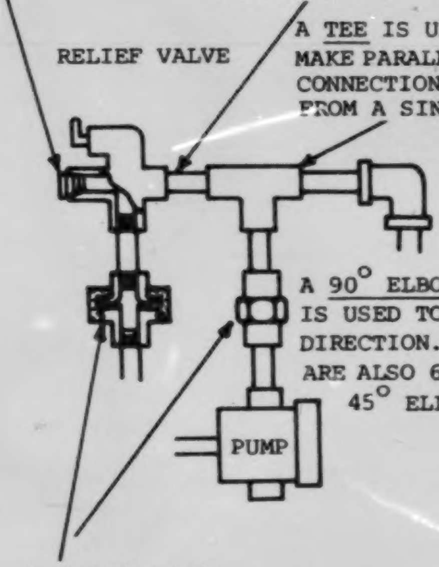
A CAP CLOSES AN OPEN PIPE END.



A STREET ELBOW (OR ELL) HAS ONE FEMALE AND ONE MALE THREAD.



A GATE OR GLOBE VALVE IS USED FOR THROTTLING FLOW.



A PIPE PLUG IS USED TO PLUG A PORT OR FITTING OPENING THAT ISN'T USED.

A NIPPLE MAKES SHORT CONNECTIONS BETWEEN COMPONENTS AND/OR FITTINGS.

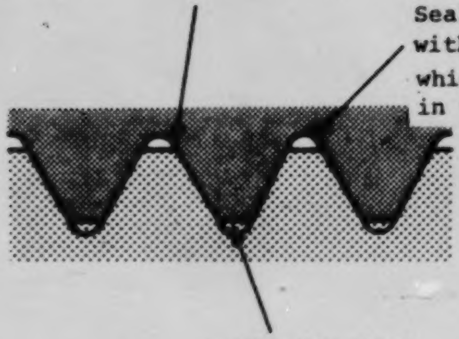
A TEE IS USED TO MAKE PARALLEL CONNECTIONS FROM A SINGLE PIPE.

A 90° ELBOW OR ELL IS USED TO CHANGE DIRECTION. THERE ARE ALSO 60° AND 45° ELLS.

A UNION HAS TWO THREADED FITTINGS PLUS AN EXTERNAL NUT TO PERMIT MAKING OR BREAKING A JOINT WITHOUT TURNING THE PIPE.

Standard Pipe Threads - American Standard

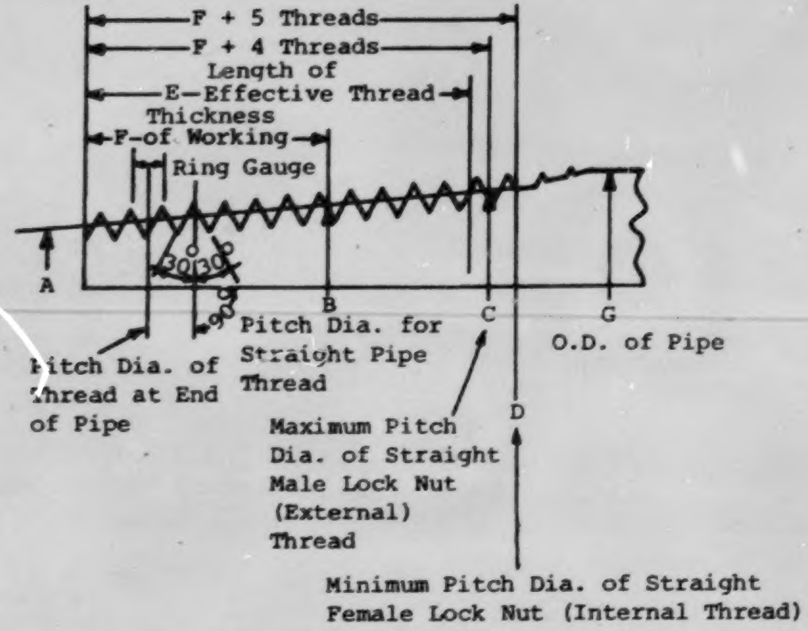
IN STANDARD PIPE THREADS, THE FLANKS COME IN CONTACT FIRST.



Seal tip of spiral thread with pipe dope. A sealant which fills groove space in threads during assembly.

THERE CAN BE A SPIRAL CLEARANCE AROUND THE THREADS.

STANDARD PIPE DIMENSIONS
(See Values On Next Page)

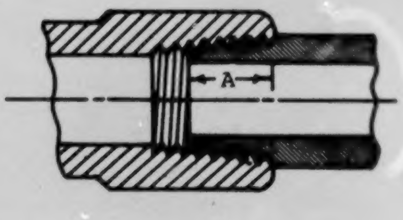

F + 5 Threads
F + 4 Threads
E—Effective Length of Thread
F—Thickness of Working Ring Gauge
30
30
90
A
B
C
G
D
Pitch Dia. of Thread at End of Pipe
Pitch Dia. for Straight Pipe Thread
O.D. of Pipe
Maximum Pitch Dia. of Straight Male Lock Nut (External) Thread
Minimum Pitch Dia. of Straight Female Lock Nut (Internal Thread)

THREAD DIMENSIONS—INCHES

SIZE	A	B①	C	D	E②	F③	G	Depth of Thread	Pitch of Thread	Threads per Inch
⅛	.36351	.37476	.3840	.3863	.2638	.180	.405	.02963	.03704	27
¼	.47739	.48989	.5038	.5073	.4018	.200	.540	.04444	.05556	18
⅜	.61201	.62701	.6409	.6444	.4078	.240	.675	.04444	.05556	18
½	.75843	.77843	.7963	.8008	.5337	.320	.840	.05714	.07143	14
¾	.96768	.98887	1.0067	1.0112	.5457	.339	1.050	.05714	.07143	14
1	1.21363	1.23863	1.2604	1.2658	.6828	.400	1.315	.06957	.08696	11½
1¼	1.55713	1.58338	1.6051	1.6106	.7068	.420	1.660	.06957	.08696	11½
1½	1.79609	1.82234	1.8441	1.8495	.7235	.420	1.900	.06957	.08696	11½
2	2.26902	2.29627	2.3180	2.3234	.7565	.436	2.375	.06957	.08696	11½
2½	2.71953	2.76216	2.7934	2.8012	1.1375	.682	2.875	.100	.12500	8
3	3.34062	3.38850	3.4198	3.4276	1.2000	.766	3.500	.100	.12500	8
3½	3.83750	3.88881	3.9201	3.9279	1.2500	.821	4.000	.100	.12500	8
4	4.33438	4.38712	4.4184	4.4262	1.3000	.844	4.500	.100	.12500	8
5	5.39073	5.44929	5.4805	5.4884	1.4063	.937	5.563	.100	.12500	8
6	6.44609	6.50597	6.5372	6.5450	1.5125	.958	6.625	.100	.12500	8

① Also pitch diameter at gauging notch. ② Also length of plug gauge. ③ Also length of ring gauge.

INFORMATION ABOVE TAKEN FROM AMERICAN STANDARD FOR PIPE THREADS, A.S.A.–B2.1

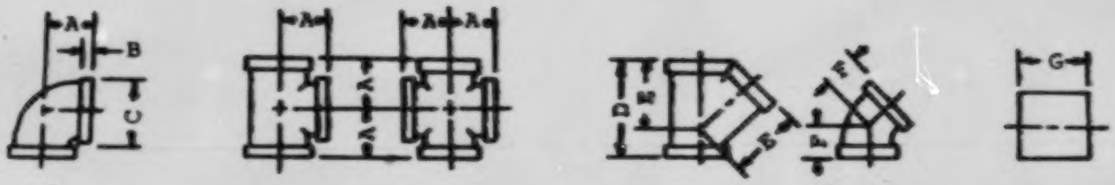


THREAD ENGAGEMENT

SIZE	1/8	1/4	3/8	1/2	3/4	1	1¼	1½	2	2½	3	3½	4	5	6
A	1/4	3/8	3/8	7/16	6/16	7/16	5/8	5/8	3/4	7/8	15/16	17/16	9/8	5/4	21/16

NO ALLOWANCE FOR VARIATION IN TAPPING AND THREADING

AMERICAN STANDARD 150 LB. MALLEABLE IRON SCREWED FITTINGS.

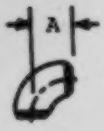


90° ELBOW TEE CROSS LATERAL 45° ELBOW COUPLING

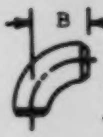
Nominal Pipe Size	Centre to End, Elbows, Tees, and Crosses A	Width of Band B	Outside Dia. of Band C	Length of Lateral D	Centre of Intersection to End of Lateral E	Centre to End, 45° Elbows F	Length of Coupling G
1/8	.69	.200	.693	---	---	---	.96
1/4	.81	.215	.844	---	---	.73	1.06
3/8	.95	.230	1.015	1.93	1.43	.80	1.16
1/2	1.12	.249	1.197	2.32	1.71	.88	1.34
3/4	1.31	.273	1.458	2.77	2.05	.98	1.52
1	1.50	.302	1.771	3.28	2.43	1.12	1.67
1 1/4	1.75	.341	2.153	3.94	2.92	1.29	1.93
1 1/2	1.94	.368	2.427	4.38	3.28	1.43	2.15
2	2.25	.422	2.963	5.17	3.93	1.68	2.53
2 1/2	2.70	.478	3.589	6.25	4.73	1.95	2.88
3	3.08	.548	4.285	7.26	5.55	2.17	3.18
3 1/2	3.42	.604	4.843	---	---	2.39	3.43
4	3.79	.661	5.401	8.98	6.97	2.61	3.69
5	4.50	.780	6.583	---	---	3.05	---
6	5.13	.900	7.767	---	---	3.46	---

All dimensions in inches.

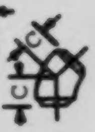
125 LB. AMERICAN STANDARD WROUGHT STEEL BUTT WELDING FITTINGS.



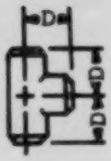
ELBOW
SHORT
RADIUS



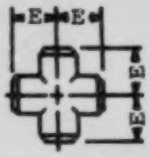
ELBOW
LONG
RADIUS



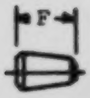
45° ELBOW
LONG
RADIUS



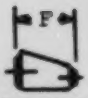
TEE



CROSS



REDUCER

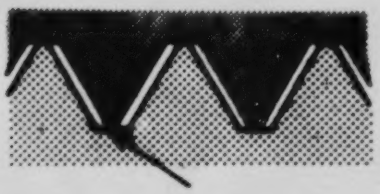


ECCENTRIC
REDUCER

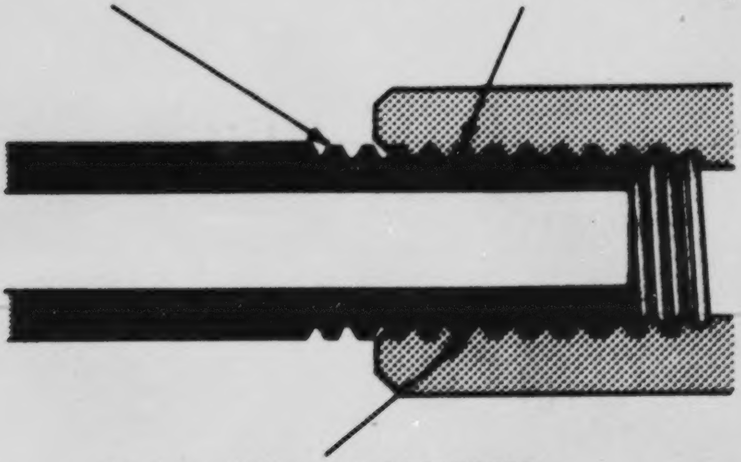
Nominal Pipe Size	Centre to End of Short Radius Elbow A	Centre to End of Long Radius Elbow B	Centre to End of 45° Long Radius Elbow C	Centre to End of Tees D	Centre to End of Cross E	Length of Reducer Largest End F
1	1	1 1/2	7/8	1 1/2	1 1/2	2
1 1/4	1 1/4	1 7/8	1	1 7/8	1 7/8	2
1 1/2	1 1/2	2 1/4	1 1/8	2 1/4	2 1/4	2 1/2
2	2	3	1 3/8	2 1/2	2 1/2	3
2 1/2	2 1/2	3 3/4	1 3/4	3	3	3 1/2
3	3	4 1/2	2	3 3/8	3 3/8	3 1/2
3 1/2	3 1/2	5 1/4	2 1/4	3 3/4	3 3/4	4
4	4	6	2 1/2	4 1/8	4 1/8	4
5	5	7 1/2	3 1/8	4 7/8	4 7/8	5
6	6	9	3 3/4	5 5/8	5 5/8	5 1/2
8	8	12	5	7	7	6
10	10	15	6 1/4	8 1/2	8 1/2	7
12	12	18	7 1/2	10	10	8

All dimensions in inches.

HYDRAULIC SCREW THREADS



IN DRY-SEAL THREADS, THE ROOTS AND CRESTS ENGAGE FIRST, ELIMINATING SPIRAL CLEARANCE.



THE TAPERED MALE THREAD ON THE SECTION OF PIPE. . .

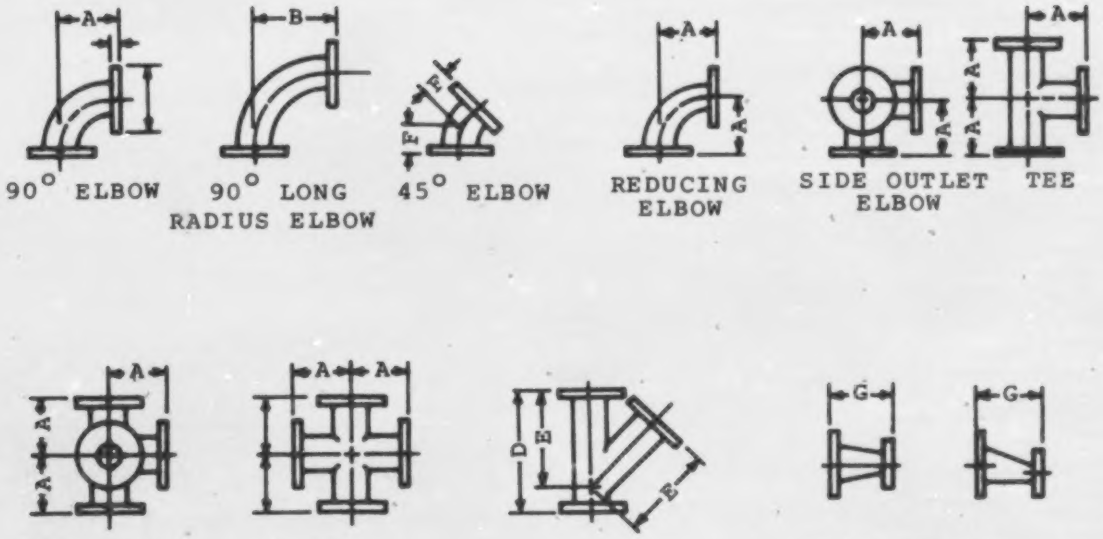
SCREWS INTO THE FEMALE THREAD IN THE FITTING OR HYDRAULIC COMPONENT. THIS THREAD ALSO IS TAPERED.

AS THE JOINT IS TIGHTENED, AN INTERFERENCE OCCURS BETWEEN THE THREADS, SEALING THE JOINTS.

FLANGED FITTINGS

Pipe fittings are made with flanged, welded or screwed and/or soldered connections.

Typical Flanged Fittings
(Dimensions on Next Page)



90° ELBOW

90° LONG RADIUS ELBOW

45° ELBOW

REDUCING ELBOW

SIDE OUTLET ELBOW

TEE

SIDE OUTLET TEE

CROSS

LATERAL

REDUCER

ECCENTRIC REDUCER

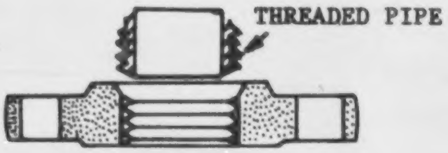
Table of Dimensions are for American Standard 125 lb flanged cast iron fittings.

Nominal Pipe Size	Centre to End, Elbows, Tees, and Crosses A	Centre to End of Long Radius Elbow B	Flange Dia. C	Length of Lateral D
1	3 1/2	5	4 1/4	7 1/2
1 1/4	3 3/4	5 1/2	4 5/8	8
1 1/2	4	6	5	9
2	4 1/2	6 1/2	6	10 1/2
3	5 1/2	7 3/4	7 1/2	13
3 1/2	6	8 1/2	8 1/2	14 1/2
5	7 1/2	10 1/4	10	17
6	8	11 1/2	11	18
8	9	14	13 1/2	22
10	11	16 1/2	16	25 1/2
12	12	19	19	30

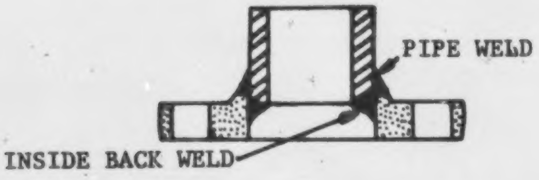
Centre of Intersection to End of Lateral E	Centre to End of 45° Elbow F	Length of Reducer G	Flange Thickness H Min.	No. of Bolts	Dia. of Bolts
5 3/4	1 3/4	---	7/16	4	1/2
6 1/4	2	---	1/2	4	1/2
7	2 1/4	---	9/16	4	1/2
8	2 1/2	5	5/8	4	5/8
10	3	6	3/4	4	5/8
11 1/2	3 1/2	6 1/2	13/16	8	5/8
13 1/2	4 1/2	8	15/16	8	3/4
14 1/2	5	9	1	8	3/4
17 1/2	5 1/2	11	1 1/8	8	3/4
20 1/2	6 1/2	12	1 3/16	12	7/8
24 1/2	7 1/2	14	1 1/4	12	7/8

All dimensions in inches.

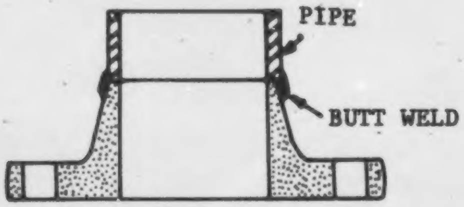
Pipe sections with flanged fittings are connected to other pipe systems using special screwed, welded, slip on, or weld neck flanges.


THREADED PIPE

THREADED FLANGE
1/16 " RAISED FACE


PIPE WELD
INSIDE BACK WELD

SLIP-ON WELDING FLANGE FLAT FACE

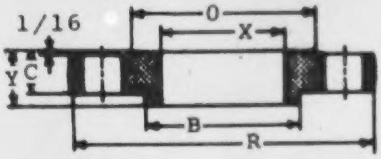

PIPE
BUTT WELD

WELDING NECK FLANGE FLAT FACE

Flanges are rated for pressure and temperature. Each class, 125 lb , 150 lb , 600 lb , ... etc., indicates the pounds per square inch pressure rating at a specific temperature. Flanges will deform if over heated or over pressured, allowing gaskets between flanges to fail.

150 POUND ANSI STANDARD

Carbon Steel Pressure	150 PSI @ 500°F
Temperature Ratings	275 PSI @ 100°F



SLIP-ON WELDING FLANGE 1/16" RAISED FACE

AMERICAN STANDARDS ASSOCIATION LISTS THE DIMENSION FOR EACH FLANGE SIZE AND TYPE.

Nominal Pipe Size	Outside Diameter	Thickness	Diameter of Hub	Length Through Hub	Bore Min.		Diameter of Raised Face	Drilling Template 150 Pound			Weight, Lbs., Approx. Slip-On Flange	Weight, Lbs., Approx. Lapped Flange
					Slip-On Welding	Lapped		No. Bolt-Studs	Diam. Bolt-Studs*	Diam. Bolt Circle		
	O	C	X	Y	B	B	R					
½	3½	7/16	1 3/16	⅝	.88	.90	1⅜	4	½	2⅜	1.	1.1
¾	3⅞	½	1½	⅝	1.09	1.11	1 11/16	4	½	2¾	1.4	1.5
1	4¼	9/16	1 15/16	11/16	1.36	1.38	2	4	½	3⅛	1.9	1.9
1¼	4⅝	⅝	2 5/16	13/16	1.70	1.72	2½	4	½	3½	2.4	2.5
1½	5	11/16	2 9/16	⅞	1.95	1.97	2⅞	4	½	3⅞	3.1	3.1
2	6	¾	3 1/16	1	2.44	2.46	3⅝	4	⅝	4¾	4.6	5.3
2½	7	⅞	3 9/16	1⅛	2.94	2.97	4⅛	4	⅝	5½	7.4	7.9
3	7½	15/16	4¼	1 3/16	3.57	3.60	5	4	⅝	6	9	9.4
3½	8½	15/16	4 13/16	1¼	4.07	4.10	5½	8	⅝	7	10.5	9.5
4	9	15/16	5 5/16	1 5/16	4.57	4.60	6 3/16	8	⅝	7½	11.6	13
5	10	15/16	6 7/16	1 7/16	5.66	5.69	7 5/16	8	¾	8½	13.9	13.8
6	11	1	7 9/16	1 9/16	6.72	6.75	8½	8	¾	9½	14.4	16.6
8	13½	1⅛	9 11/16	1¾	8.72	8.75	10⅝	8	¾	11¾	27	25
10	16	1 3/16	12	1 15/16	10.88	10.92	12¾	12	⅞	14¼	37.9	37.9
12	19	1¼	14⅜	2 3/16	12.88	12.92	15	12	⅞	17	59.6	58.4

DIMENSIONS ARE IN INCHES

DIMENSIONAL STANDARDS FOR 150 LB RAISED FACE FLANGES

VALVES

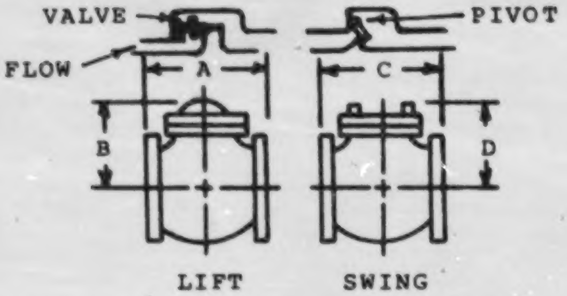
Valves are used to stop flow, control flow rates, limit fluid pressure and control flow direction.

Nominal Pipe Size	Outside Diameter	Thickness	Diameter Of Hub	Length Through Hub	Bore Min.		Diameter of Raised Face	Drilling Template 150 Pound			Weight, lbs, Approx. Slip-on Flange	Weight, lbs, Approx. Lapped Flange
					Slip-On Welding	Lapped		No. Bolt-Studs	Diam. Bolt-Studs	Diam. Bolt Circle		
1/2	3 1/2	7/16	1 3/16	5/8	.88	.90	1 3/8	4	1/2	2 3/8	1.	1.1
3/4	3 7/8	1/2	1 1/2	5/8	1.09	1.11	1 11/16	4	1/2	2 3/4	1.4	1.5
1	4 1/4	9/16	1 15/16	11/16	1.36	1.38	2	4	1/2	3 1/8	1.9	1.9
1 1/4	4 5/8	5/8	2 5/16	13/16	1.70	1.72	2 1/2	4	1/2	3 1/2	2.4	2.5
1 1/2	5	11/16	2 9/16	7/8	1.95	1.97	2 7/8	4	1/2	3 7/8	3.1	3.1
2	6	3/4	3 1/16	1	2.44	2.46	3 5/8	4	5/8	4 3/4	4.6	5.3
2 1/2	7	7/8	3 9/16	1 1/8	2.94	2.97	4 1/8	4	5/8	5 1/2	7.4	7.9
3	7 1/2	15/16	4 1/4	1 8/16	3.57	3.60	5	4	5/8	6	9	9.4
3 1/2	8 1/2	15/16	4 13/16	1 1/4	4.07	4.10	5 1/2	8	5/8	7	10.5	9.5
4	9	15/16	5 5/16	1 5/16	4.57	4.60	6 3/16	8	5/8	7 1/2	11.6	13
5	10	15/16	6 7/16	1 7/16	5.66	5.69	7 5/16	8	3/4	8 1/2	13.9	13.8
6	11	1	7 9/16	1 9/16	6.72	6.75	8 1/2	8	3/4	9 1/2	14.4	16.6
8	13 1/2	1 1/8	9 11/16	1 3/4	8.72	8.75	10 5/8	8	3/4	11 3/4	27	25
10	16	1 3/16	12	1 15/16	10.88	10.92	12 3/4	12	7/8	14 1/4	37.9	37.9
12	19	1 1/4	14 3/8	2 3/16	12.88	12.92	15	12	7/8	17	59.6	58.4

DIMENSIONS ARE IN INCHES

Common valve types with dimensions for 125 **lb** cast iron

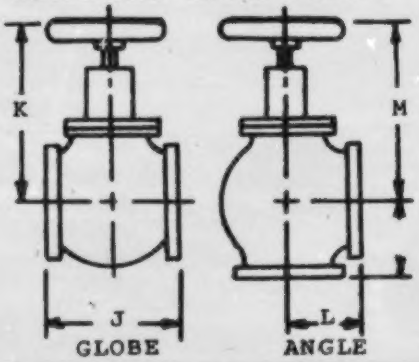
CHECK VALVES



VALVE DIMENSIONS
IN INCHES

Size	Lift Check			Swing Check		
	A		B	C		D
	Screwed	Flanged		Screwed	Flanged	
2	6 1/2		3 1/2	6 1/2	8	4 1/4
2 1/2	7		4 1/4	7	8 1/2	4 3/16
3	8	9 1/2	5	8	9 1/2	5 1/16
3 1/2				9	10 1/2	5 13/16
4	10	11 1/2	6 1/4	10	11 1/2	6 3/16
5		13	7	11 1/4	13	7 3/16
6		14	8 1/4	12 1/2	14	7 1/2
8					19 1/2	10 3/16
10					24 1/2	12 1/8

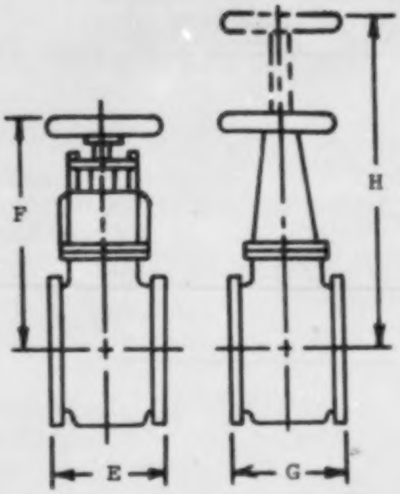
GLOBE AND ANGLE VALVES



VALVE DIMENSIONS
IN INCHES

Size	Globe			Angle		
	J		K	L		M
	Screwed	Flanged		Screwed	Flanged	
2	4 3/4	7	9 7/16	3 1/2	3 7/8	10 3/8
2 1/2	5 1/2	7 1/2	11 1/16	3 7/8	4 1/2	12 1/16
3	6	8	12 3/8	4 11/16	4 5/8	13 11/16
3 1/2	6 5/8	8 1/2	13 3/16	5	5 3/8	13 5/8
4	7 1/8	9	15 1/4	6	5 7/8	14 7/8
5	8 1/8	10	17 1/4	6 5/16	6 1/2	17 11/16
6	9	10 1/2	18 13/16	8	8 [illegible]	19 3/16
8	10	11 1/2	22 1/8		9 1/4	22 3/4
10		13	24 3/4		10 5/8	24 15/16

GATE VALVES

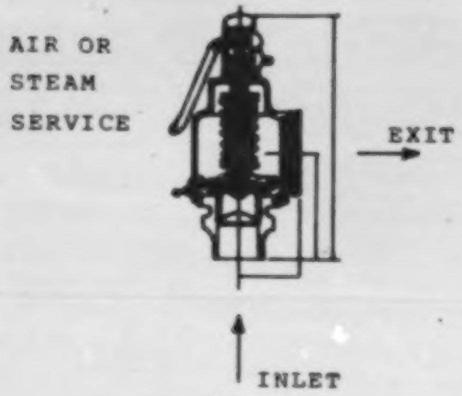


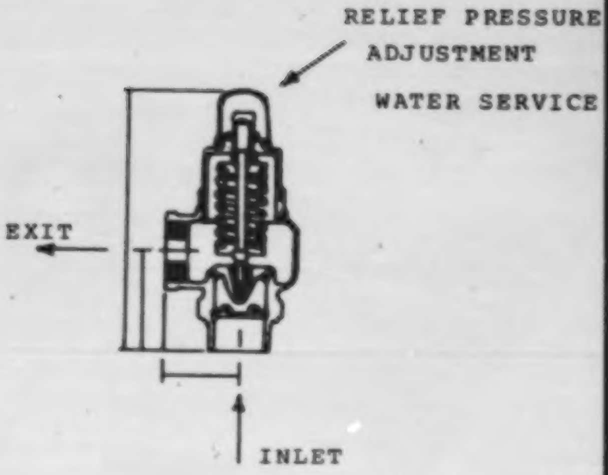
VALVE DIMENSIONS IN INCHES

Size	Non-Rising Spindle			Rising Spindle		
	E		F	G		H
	Screwed	Flanged		Screwed	Flanged	
1 1/2	4 3/4		10 1/2	4 3/4		13 1/8
2	4 3/4	7	10 1/2	4 3/4	7	13 1/8
2 1/2	5 1/2	7 1/2	11 3/16	5 1/2	7 1/2	14 1/2
3	6	8	12 5/8	6	8	16 5/8
3 1/2	6 5/8	8 1/2	13 5/16	6 5/8	8 1/2	18 7/16
4	7 1/8	9	15 1/4	7 1/8	9	21 1/16
5	8 1/8	10	17 7/8	8 1/8	10	25
6	9	10 1/2	20 3/16	9	10 1/2	29 1/4
8	10	11 1/2	24	10	11 1/2	37 1/4
10		13	28 3/16		13	44 1/8

SPECIAL VALVES

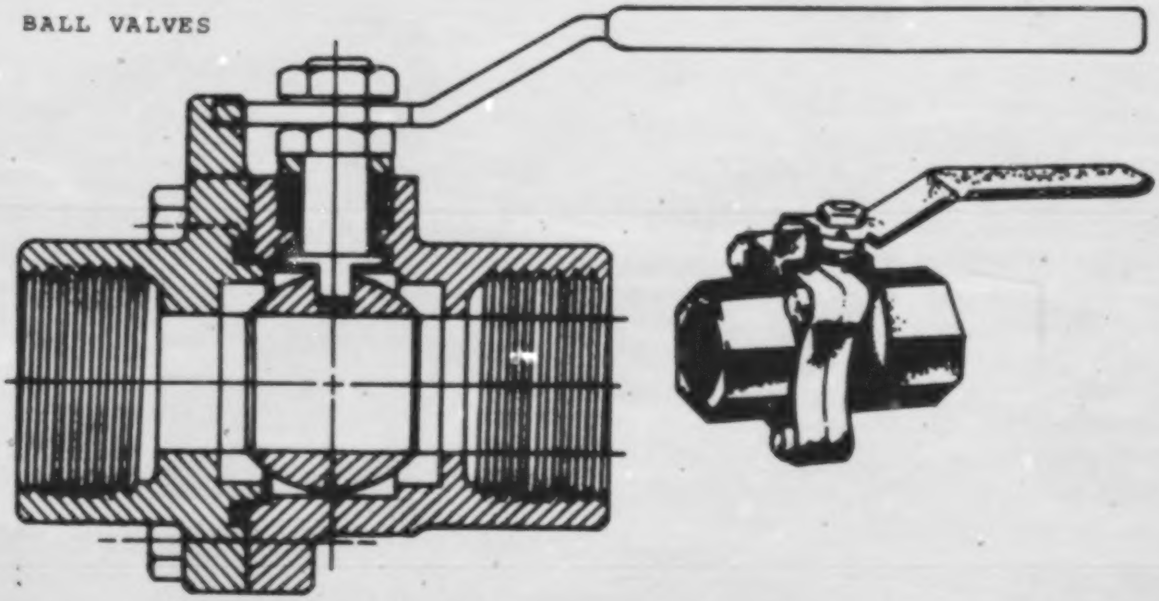
SAFETY OR RELIEF VALVES

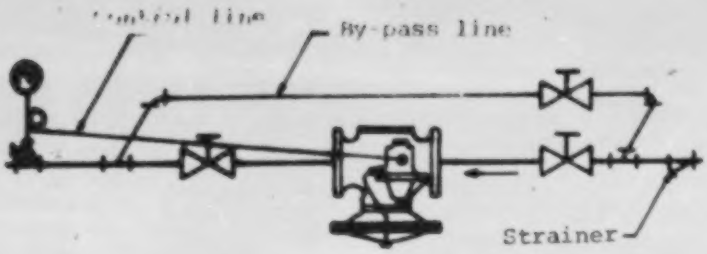

AIR OR
STEAM
SERVICE
EXIT
INLET


RELIEF PRESSURE
ADJUSTMENT
WATER SERVICE
EXIT
INLET

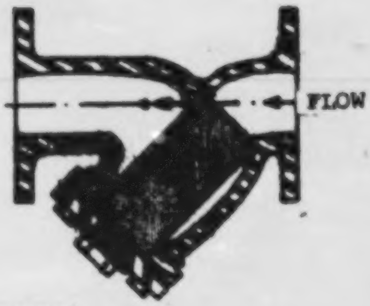
Coded relief valves are designed to meet ASME boiler code specifications. Refer to ASME boiler code and read standards for fired or unfired pressure vessels.

BALL VALVES



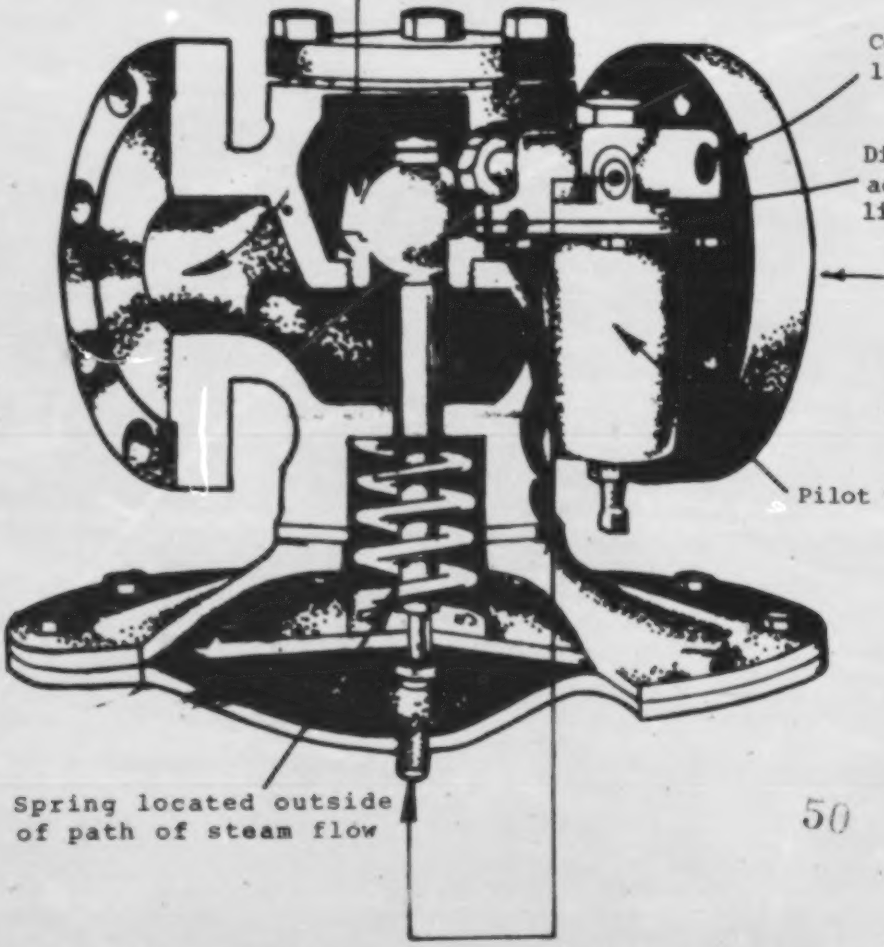

Control line
By-pass line
Inlet
Flow
Strainer

Strainers are used before control valves and pumps.



Control valve regulates pressure at control point.

Strainers collect particles of scale which may jamb valve open.


Control
line port
Diaphragm
actuator
lime port
Valve inlet
Pilot valve
Spring located outside
of path of steam flow

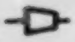
LABORATORY SKILLS

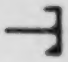
The student should work with or study piping or tubing systems and become familiar with the many types of system components and how each functions, and for what purpose they may be used.

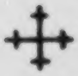
STUDENT PROBLEMS

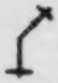
1. Identify each of the components symbolized and indicate an application for each of the components.

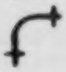
DRAWING
SYMBOL

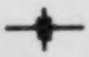
a) 

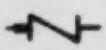
b) 

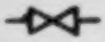
c) 

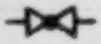
d) 

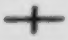
e) 

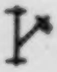
f) 

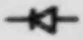
g) 

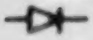
h) 

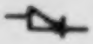
i) 

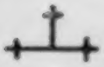
j) 

k) 

l) 

m) 

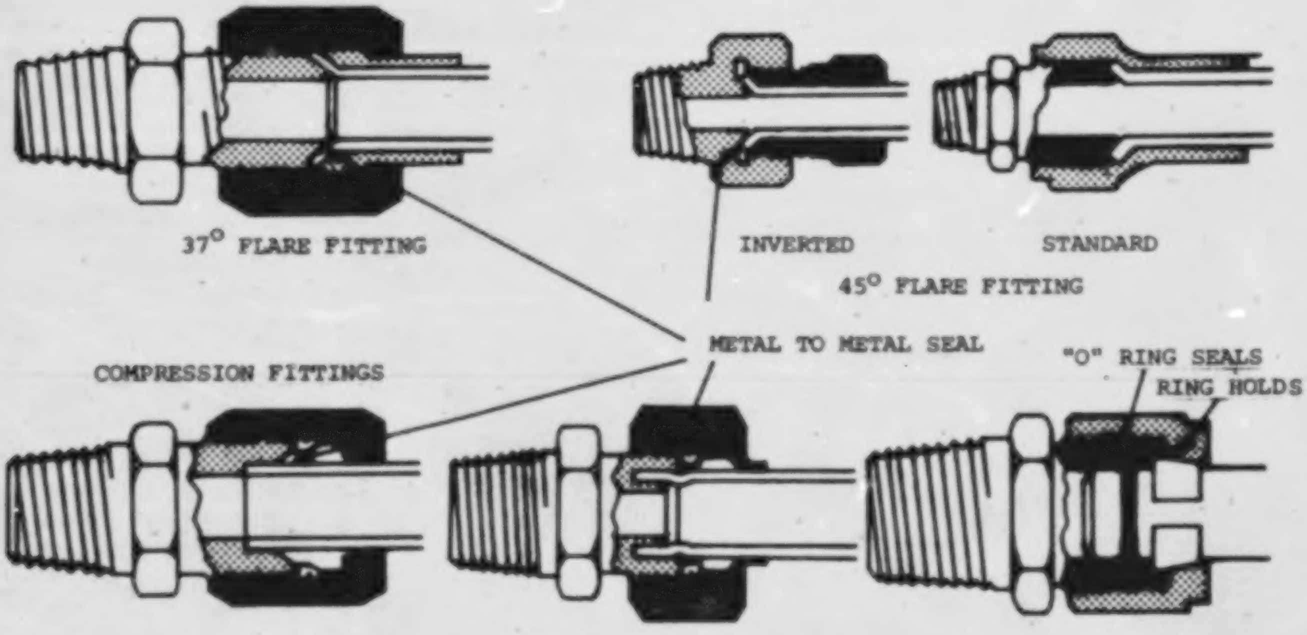
n) 

o) 

Section 4 - Tubing Systems

Tube piping systems having tubing from 1/8" O.D. and up are used on pneumatic and hydraulic control or power systems. The tubing and connectors used may be steel, copper, brass or plastic. Tubing systems consist of groupings of components for specific pressure and temperature conditions. Connectors to attach tubing to fittings are continually being improved. A few are shown below. Compression fittings are used to keep the tube from drawing out of the ferrule under high pressures.

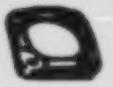
FLARE FITTINGS (1/2" TUBE AND UNDER)


37° FLARE FITTING
INVERTED
STANDARD
45° FLARE FITTING
METAL TO METAL SEAL
COMPRESSION FITTINGS
"O" RING SEALS
RING HOLDS

FERRULE COMPRESSION FITTING SLEEVE COMPRESSION FITTING "O" RING COMPRESSION FITTING

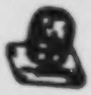
EXAMPLES OF SOME STANDARD TUBE FITTINGS

AN 756 MS 20736



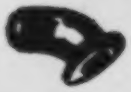
FLANGE-SWIVEL
FITTING FLANGED

AN 760 MS 20760



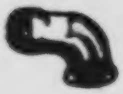
CONNECTOR-FLARED,
TUBE FLANGED,
FIXED

AN 761 MS 20761



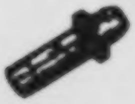
ELBOW, FLARED
TUBE, FLANGED,
SWIVEL, 45°

AN 762 MS 20782



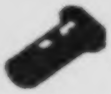
ELBOW, FLARED
TUBE, FLANGED,
SWIVEL 90°

AN 774 MS 24387



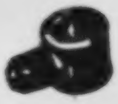
BOLT-FLARED TUBE
FITTING END
UNIVERSAL

AN 775



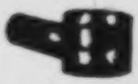
BOLT-UNIVERSAL
FITTING

AN 778



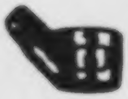
ELBOW-
UNIVERSAL 90°

AN 777



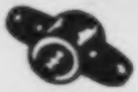
ELBOW-
UNIVERSAL 75°

AN 778



ELBOW UNIVERSAL 45°

AN 779

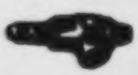


TEE-UNIVERSAL
FITTING

AN 780

NIPPLE UNION

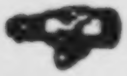
AN 783 MS 24388



TEE-FLARED TUBE,

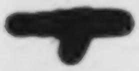
ON SIDE

AN 784 MS 24389



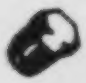
TEE-FLARED TUBE,
INTERNAL THREAD
ON RUN

AN 804 MS 24390



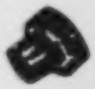
TEE-FLARED TUBE
WITH BULKHEAD ON RUN

AN 806 MS 24404



PLUG-FLARED TUBE

AM 314 MS 24391
AN814-L
(SHOWN)



PLUG & BLEEDER
SCREW THREAD

AN - AMERICAN NATIONAL STANDARD MS - MILITARY STANDARD

Parts identification for the AN and MS fittings are made with a number or letter and a color. AN and MS fittings are marked with the letters AN or MS either embossed or by impression stamping. AN fittings made from corrosion-resistant steel are marked with the letter S if fabricated from either type 304L or 347 steel and with the letter C if fabricated from either type 302, 303, 304, 316, or 321 steel. Wherever practicable, each part is also identified by the complete drawing number. In addition to the above identification, AN and MS fittings are identified by colors as follows:

AN Fittings (flared and straight thread) and MS (flared)

Aluminum alloy	Blue
Steel	Black
Aluminum bronze	Natural cadmium plate
Copper base alloys	Natural cadmium plate
Corrosion-resistant steel	None

MS Fittings (flareless)

Aluminum alloy	Green
Steel	Natural cadmium plate
21900-21901 Aluminum alloy	Brown
21900-21901 Steel	Natural cadmium plate
Ferrules 21918	Natural cadmium plate

Parts designation numbers for the AN flared tube fittings are made up of a basic part number followed by a dash number indicating the OD of the tube in sixteenths of an inch and a letter designating the material type.

Example: 815-BD

Type fitting is indicated by the basic part number.
Size fitting is indicated by the dash number.
Material is indicated by letter designation.
The MS flared type fitting designation method is the same as for AN flared fittings. The material designation letter normally follows the basic part number; however, the Military Specifications list also follows the dash number.

Material designations are as follows:

No letter	Steel
D	Aluminum alloy
B	Copper alloy
C	Corrosion-resistant steel (302, 303, 304, 316 and 321)
S	Corrosion-resistant steel (304L and 347)

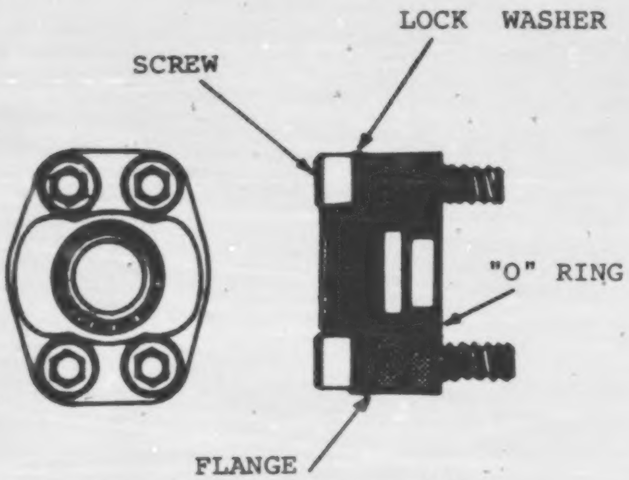
When the fitting is available in steel or aluminum only, the designations are as follows:

No letter	Steel
D	Aluminum alloy

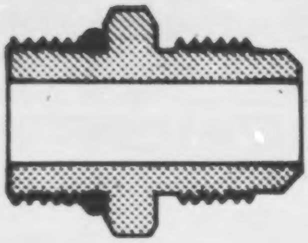
When the fitting is available in copper alloy or aluminum only, the designations are as follows:

No letter	Copper alloy
D	Aluminum alloy

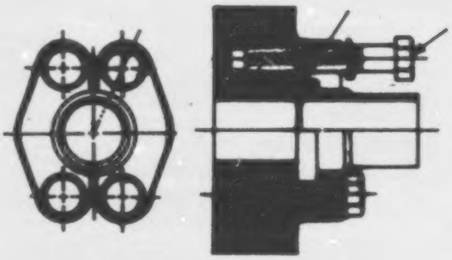
"O" RING SEALED CONNECTORS (1/2 " Tube and Over)


LOCK WASHER
SCREW
"O" RING
FLANGE

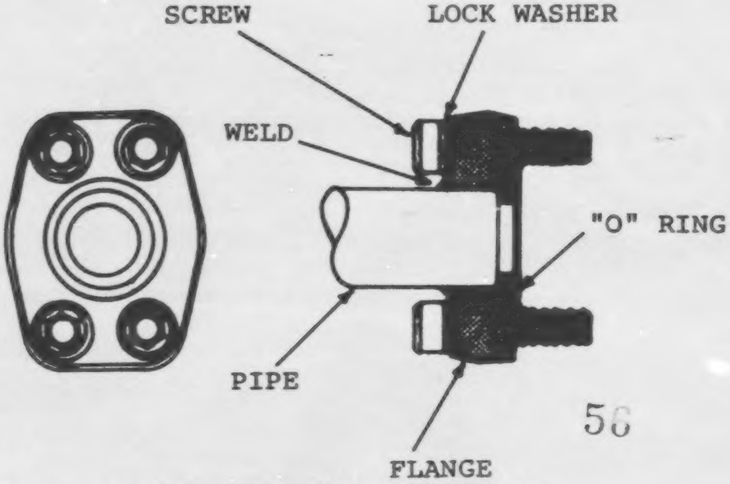
PIPE THREADED O-RING FLANGE
3000 PSI ONLY



STRAIGHT THREAD "O" RING
CONNECTOR



FOUR BOLT SPLIT FLANGE
500 PSI, 3000 PSI, 6000 PSI


SCREW
LOCK WASHER
WELD
"O" RING
PIPE
FLANGE

SOCKET WELD O-RING FLANGE

LABORATORY ACTIVITY AND SKILLS

Tubing systems around a school or industry should be studied to see the many systems used.

EXAMPLES

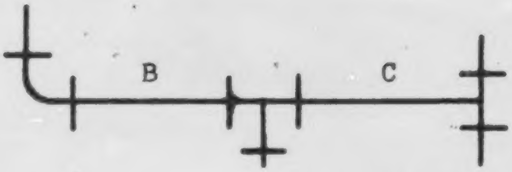
Compressed air system
Pneumatic controls on heating system
Copper water piping
Hydraulic lines in machine shop or on tensile testing machine
Hose connections on car hydraulic, steering, refrigeration, and vacuum lines
Chemistry lab plastic tubing

STUDENT PROBLEMS

1. Determine the pipe lengths needed to connect the two fittings with 150 lb malleable iron fittings. 1" size.

B = ____________

C = ____________



2. For the same piping system shown in question 1, determine the pipe lengths for a system with 125 lb butt welded fittings of wrought steel. The pipe size is one inch.

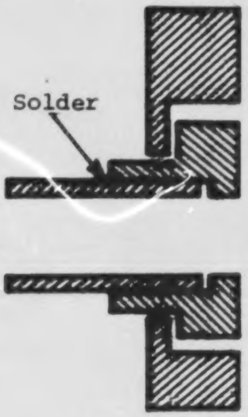
B = ____________

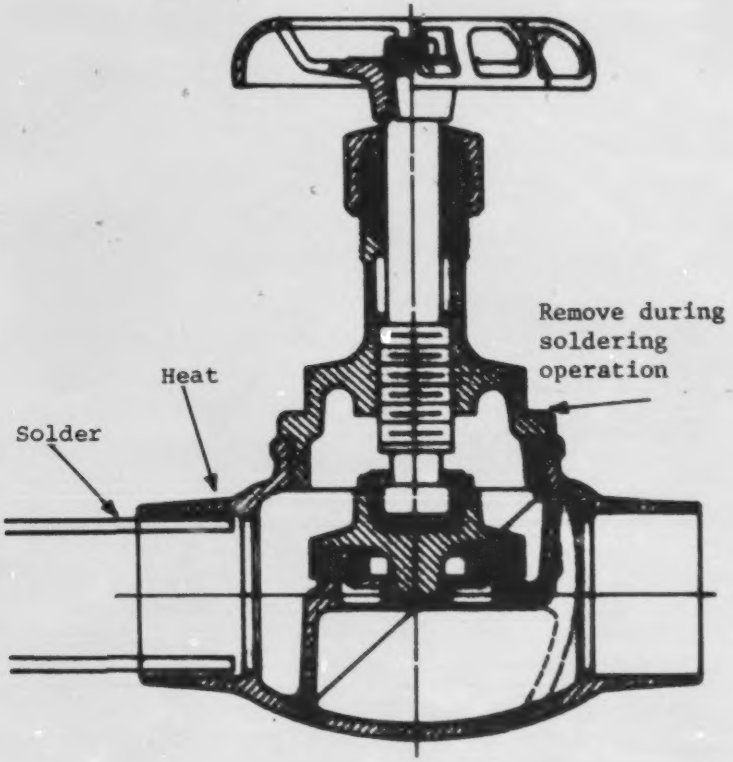
C = ____________

Section 5 - Soldering and Bonding of Copper, Steel, and Plastic Pipe Tubing Systems

Tubing systems for high pressure and for permanent assemblies utilize a soldered, brazed, or cemented joint. These connections do not require reducing the tube wall thickness by threading or allow for extrusion of the tube from a connector due to high pressure or vibration.

Soldering and brazing utilizes a sleeved connector which is bonded to the tube with a lower melting point solder or brazing alloy. The large joint area means low stress levels in the connection with maximum burst strength maintained. Joint strength is dependent on the solder's temperature and pressure rating.

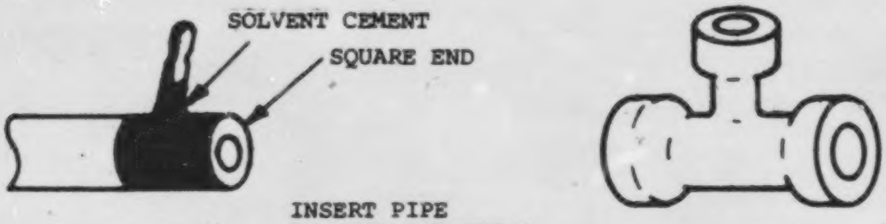




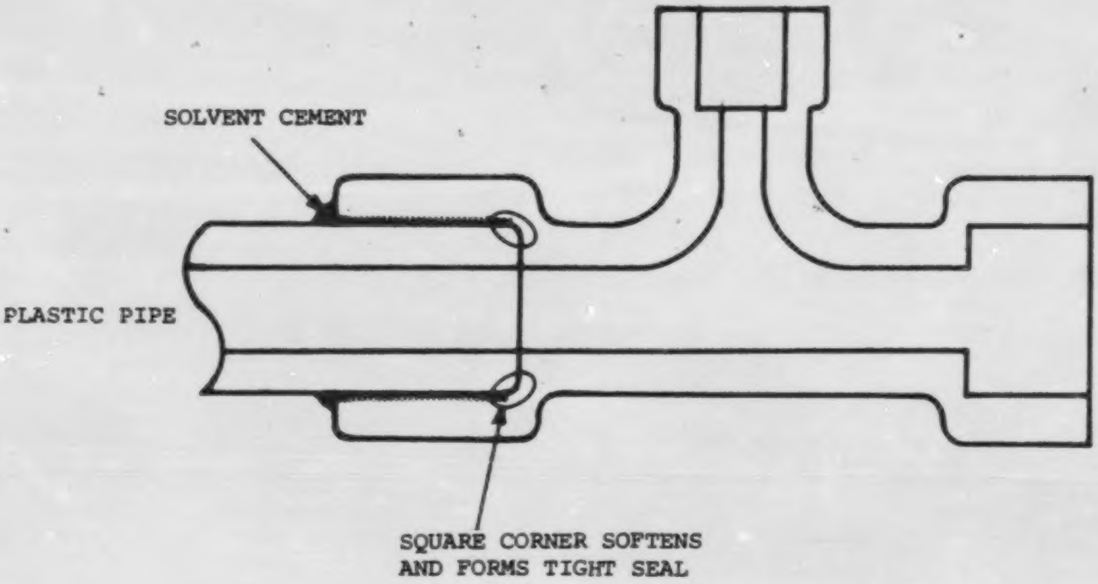
Soldered and brazed connections are normally done after removing the valve stem, seat disk and packing to prevent damage from heat.

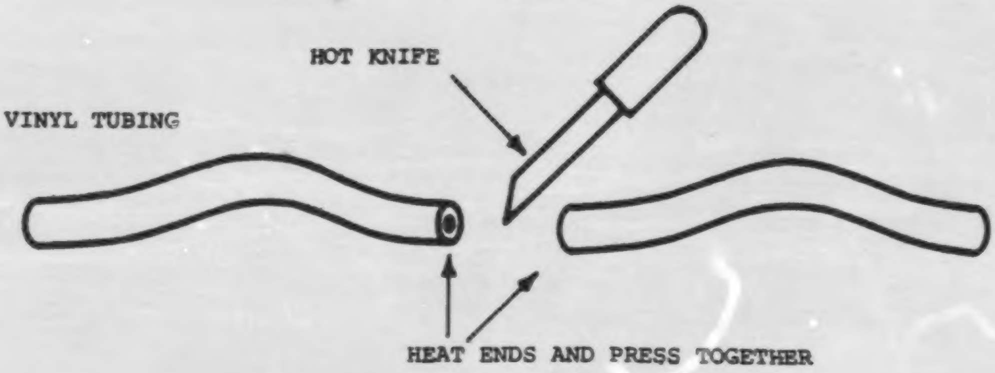
PVC Pipe

Poly-vinyl-chloride (PVC) is a plastic pipe that is cemented or melted together. Solvent cement with resin filler produces a strong tight connection.

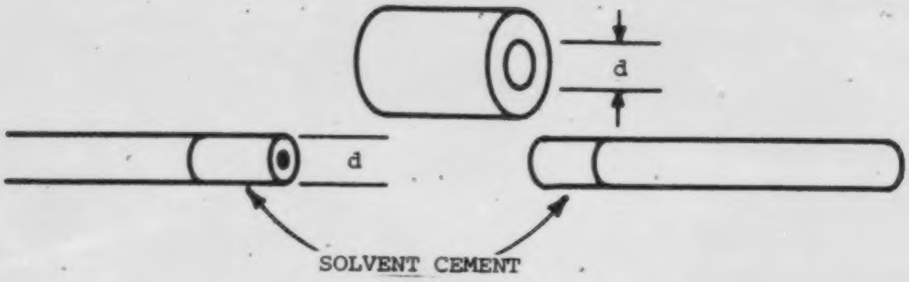

SOLVENT CEMENT
SQUARE END

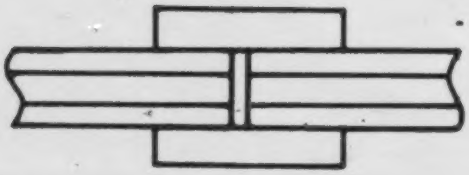
INSERT PIPE IN TUBE AND TWIST.


SOLVENT CEMENT
PLASTIC PIPE
SQUARE CORNER SOFTENS AND FORMS TIGHT SEAL


HOT KNIFE
VINYL TUBING
HEAT ENDS AND PRESS TOGETHER

Another method is solvent cementing.





FINAL CONNECTION

LABORATORY ACTIVITY AND SKILLS

Soldering and bonding of tube and pipe systems should be done by each student. Solvent cementing and hot air gun welding of plastic pipe should be tried. Refer to data in Appendix on plastic solvents and adhesives. (Table 2 and 3)

STUDENT PROBLEMS

1. PVC pipe is cemented with ____________________________.

2. Advantages of soldered and cemented tube and pipe systems are:

   ____

   ____

   ____

3. Limitations on soldered connections are:

   ____

   ____

4. Valves and components with seals and packing should be ____________________ before soldering.

5. Vinyl tubing may be connected by:

   ____

   ____

Section 6 - Gaskets and Seals

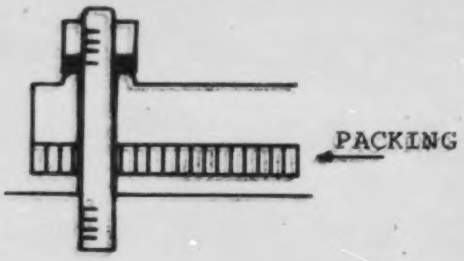
Gaskets, seals and packing are composed of resilient, metallic, ceramic, or hydrocarbon materials which will insure a liquid or gas tight seal between two mating surfaces. The gasket material has a compressive strength less than that of the mating surfaces.

Gaskets and seals are designed for two applications.

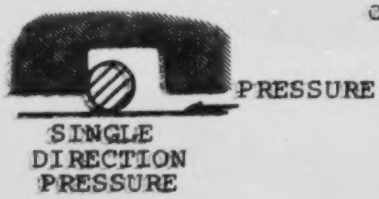
STATIC SEALS
NON-MOVING MATING
SURFACES

DYNAMIC SEALS
MOTION BETWEEN
MATING SURFACES

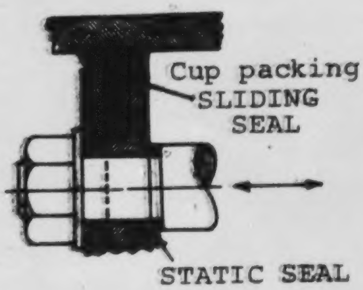
COMPRESSION SEAL

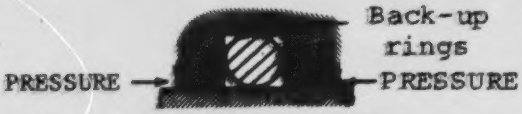


ROTATION

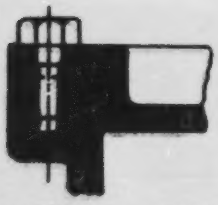

PRESSURE
SINGLE
DIRECTION
PRESSURE

OSCILLATING MOTION


Cup packing
SLIDING
SEAL
STATIC SEAL

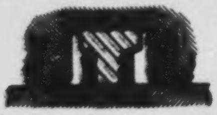

Back-up
rings
PRESSURE
PRESSURE

O-ring packing

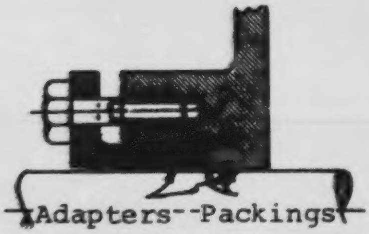


Confined packing

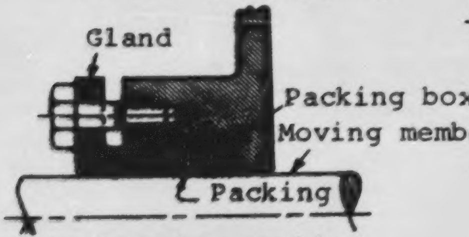
ALTERNATING PRESSURE



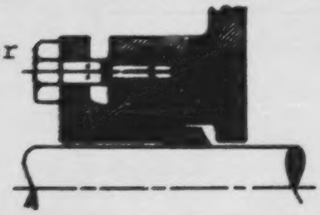
(e) T-ring packing


Adapters--Packings

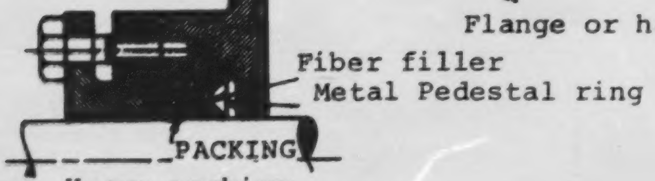
V-ring packing


Gland
Packing box
Moving member
Packing

Compression packing



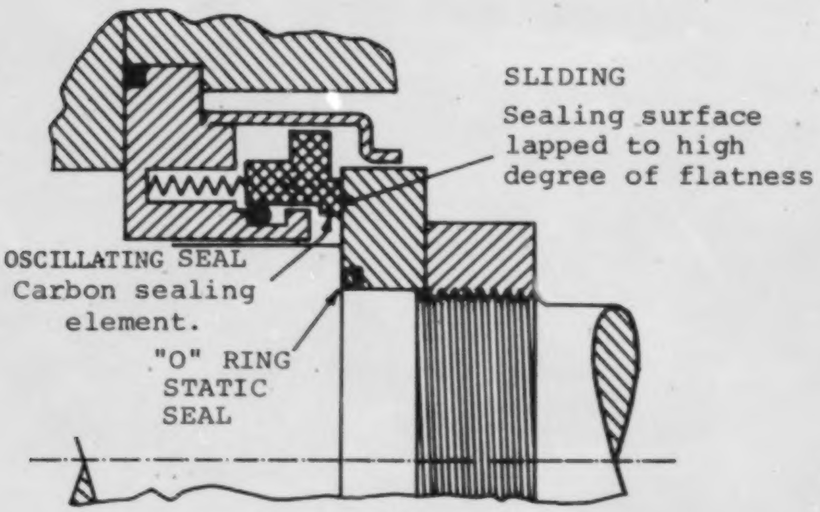
Flange or hat packing


Fiber filler
Metal Pedestal ring
PACKING

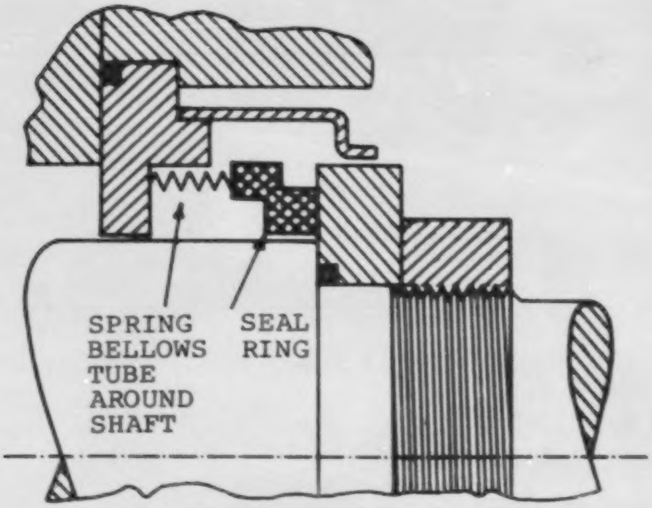
U-cup packing

MECHANICAL SEALS

Mechanical seals are designed to maintain contact between a carbon seal and a hard lapped, rotating, ceramic disk. The seal surfaces are held together with a set of springs and an "O" ring seal; high temperature applications use a spring bellows.


SLIDING
Sealing surface lapped to high degree of flatness
OSCILLATING SEAL
Carbon sealing element.
"O" RING STATIC SEAL

BELLOWS


SPRING BELLOWS TUBE AROUND SHAFT
SEAL RING

LABORATORY ACTIVITY AND SKILLS

Each student should study sales literature on materials for seals and gaskets.

Applications of the many seal types should be examined by inspecting college facilities. Some examples might be:

Old car bearing seals
Old brake cylinder piston from car
Hydraulic cylinders of any kind
Packing on valve stems
Seals on door closing systems
Pump seals and gaskets in power plant
Swimming pool filtration plant

STUDENT PROBLEMS

1. Name three styles of tubing connection systems.

   ____

   ____

   ____

2. Name two standards used in specifying tube systems.

   ____

   ____

3. 6000 PSI high pressure hydraulic tubing systems require ____________________ connections.

4. Draw a graphic diagram of a control circuit to control water pressure to a system. Use a pilot operated control valve.

CHAPTER IV

MATERIALS' PROPERTIES AND TESTING

Materials must be chosen to make items to be used for support, transmission of energy, or holding corrosive materials used in a variety of industries. Some of the major material properties needed by technicians to select items to be made can be grouped into categories of:

Mechanical properties
Chemical properties
Physical properties

Materials may be grouped by compositon. These are normally:

Ferrous Metals - Iron the major element
Strong, ductile

Non-ferrous Metals - Iron-free metals such as: aluminum, zinc, copper, tin, lead, magnesium, gold, silver
Soft, ductile

Ceramics - Oxides of metals such as:
Silicon dioxide
Aluminum oxide
Hard and brittle

Plastics and Elastomers - Organic compounds of carbon, hydrogen, and oxygen

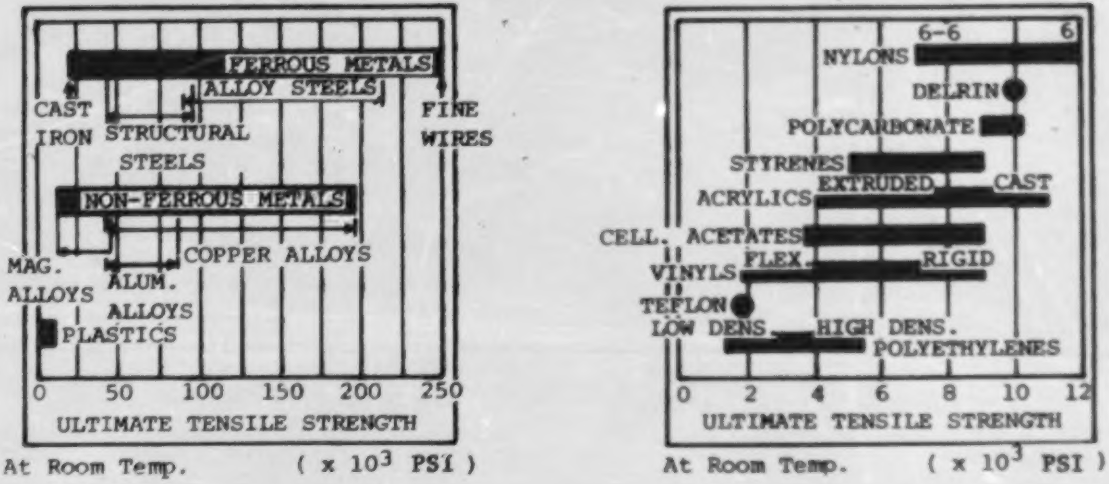
Section 1 - Material Properties and Tests

Mechanical properties include:

a) **Tensile Strength** - Strength is the load measured in pounds or newtons per unit cross-sectional area that a material can withstand before breaking. Tensile stress is then the indicator of the internal resistance to deformation of the fibers of a material when an external force is applied. The maximum tensile strength is called the ultimate strength.

$$\text{Stress} = \frac{\text{force}}{\text{cross-section area}} = \frac{\text{newtons}}{(\text{meter})^2} = \frac{\text{lb}}{\text{in}^2}$$

Typical tensile strengths of materials.



When a tensile strength test is made on a material, the initial specimen test length is accurately measured, along with a cross-sectional area. The elongation of the test section is measured for each load applied. A term called "strain" is determined by dividing specimen elongation by the initial test length (change in length/initial length), and is thus dimensionless. A plot of tensile stress versus strain is then plotted. The shape of the stress-strain curve is dependent on the type of material being tested. Standards for test specimen size and accuracy of the test equipment are available from *ASTM Standards.

YS - Yield Stress
UYP - Upper Yield Point
LYP - Lower Yield Point

DUCTILE METALS

FIG. A

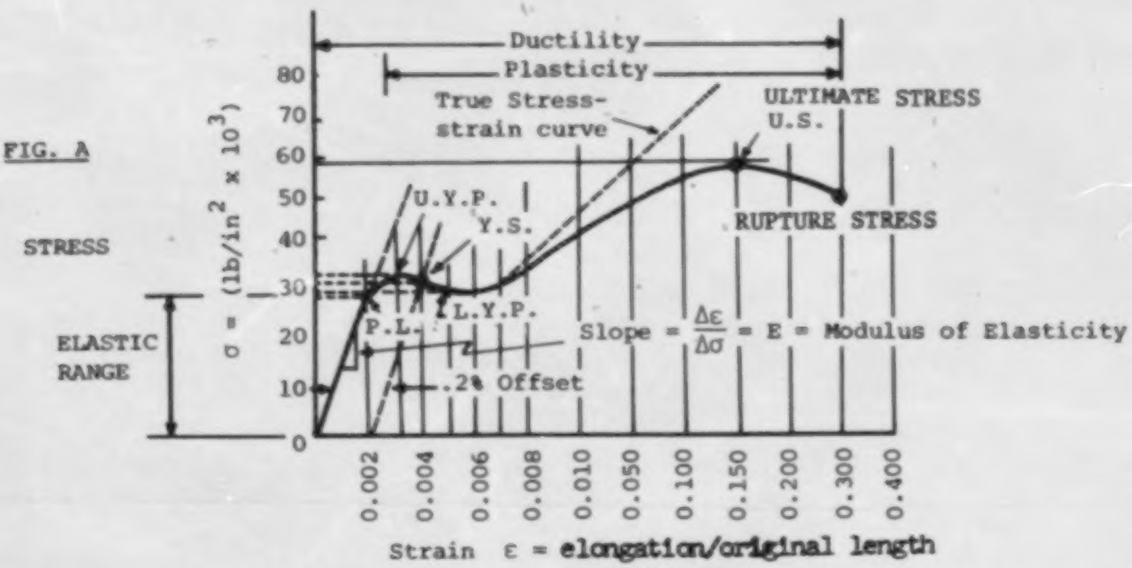
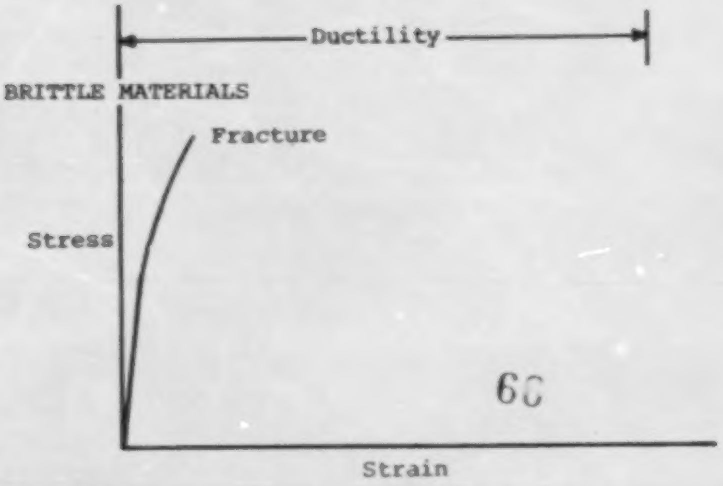
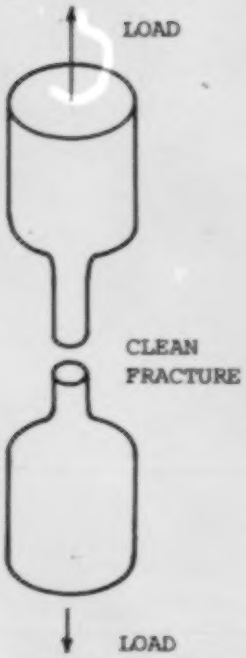


FIG. B



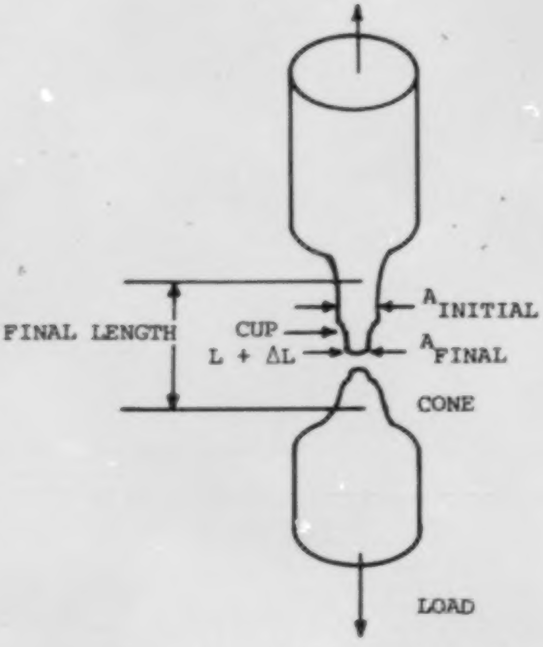
b) **Brittleness and Ductility** - Figures A and B indicate that materials may exhibit very different stress-strain curve shapes. The amount of strain a material can withstand before failure being one indication of ductility. Ductility is % elongation relative to other materials. The sudden failure of a specimen with no large change in strain before failure would indicate a brittle material. The specimen would fail with a fractured surface.



BRITTLE MATERIAL
TENSILE TEST

Indication of a brittleness

A. Clean fracture at failure point with no indicated reduction in area.



DUCTILE MATERIAL
TENSILE TEST.

Indications of ductility

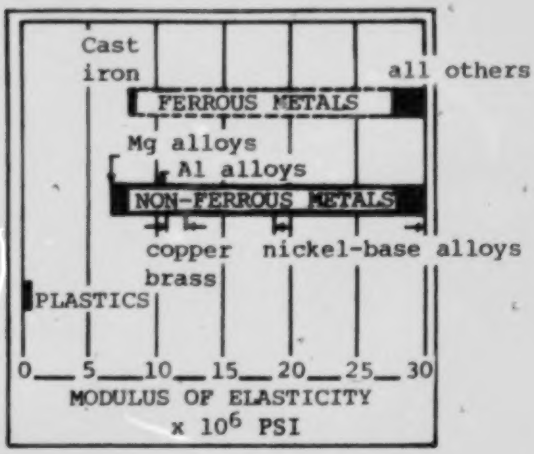
A. Necking down of failure zone.

B. % reduction in cross section area at failure.

C. $$\% \text{ elongation} = \frac{\text{Final length} - \text{Initial length}}{\text{Initial length}} \times 100\%$$

$$\left(\frac{A_{\text{Initial}} - A_{\text{Final}}}{A_{\text{Final}}}\right) \times 100\% = \%\ \text{Reduction in area}$$

c) Modulus of Elasticity - The straight line segment of the stress-strain curve is the region where stress is proportional to strain. The slope of the curve is called the modulus of elasticity. The larger the modulus of elasticity the less deflection or strain for a given stress in the material. The units for modulus of elasticity are psi or N/m^2. Strain results when a specimen is loaded.



d) Yield Strength - Ductile materials which deform before failure have a point where a small increase in stress causes a large increase in the strain that takes place in the material. The point is called the "yield stress" or "yield point." The accurate measure of yield stress is difficult, but consistent test results on ductile materials are achieved by drawing a line parallel to the straight section of the stress-strain curve at a 0.2% strain. Brittle materials may have no clearly defined yield stress but fail suddenly when the ultimate stress is reached.

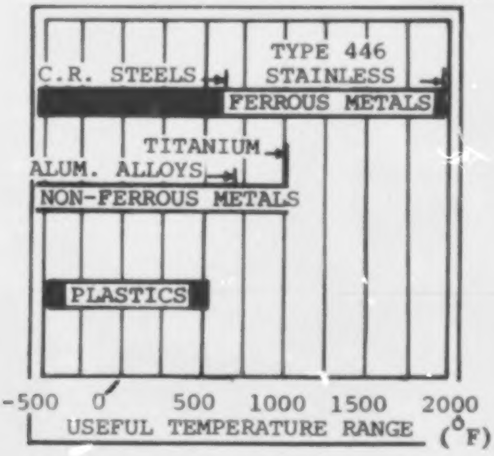
See curves Figure A and B in section.

Typical yield strengths are found in materials' handbooks.

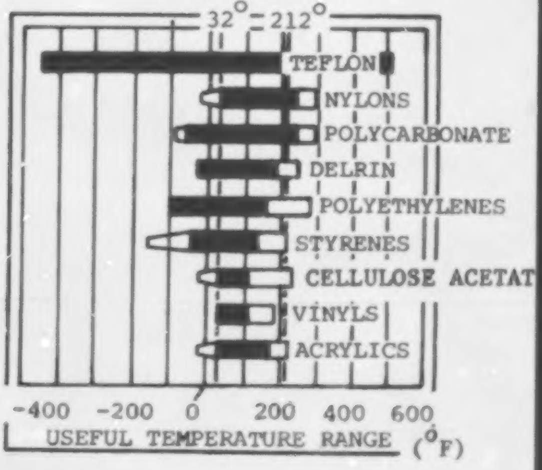
Yield strength in ductile metals is the stress level where permanent deformation exists after the load is removed. Most equipment designs require the maximum design stress called "allowable stress" to be less than the yield stress value for the material.

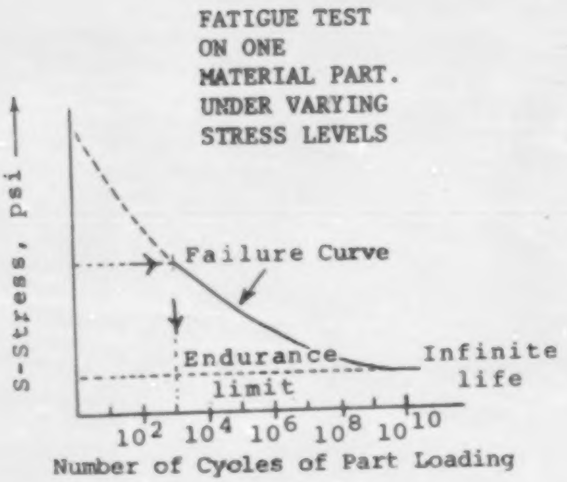
e) Elasticity and Plasticity - Elasticity is indicated by the stress level or strain obtainable before permanent deformation occurs.

Plasticity is the amount of permanent strain the material can exhibit before rupture. A plastic material can exhibit more permanent strain than a less plastic material. We can have degrees of plasticity or elasticity. The temperature of a material and the rate of loading a material will affect the properties of elasticity and plasticity. Material tests must be made under conditions similar to the actual application.



Plastics

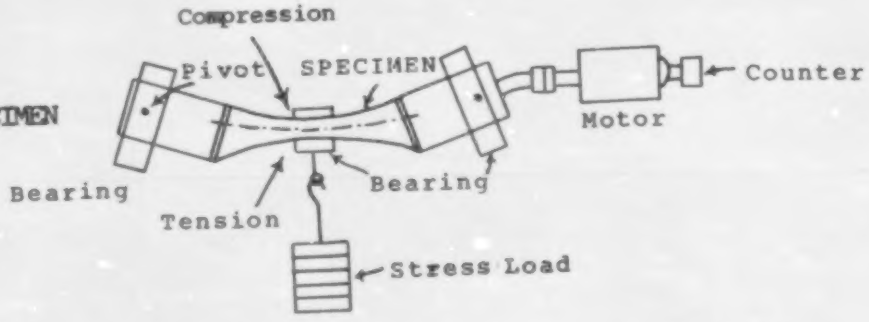




Selecting a design stress, the number of cycles of part loading before failure can be determined using the fatigue test data.

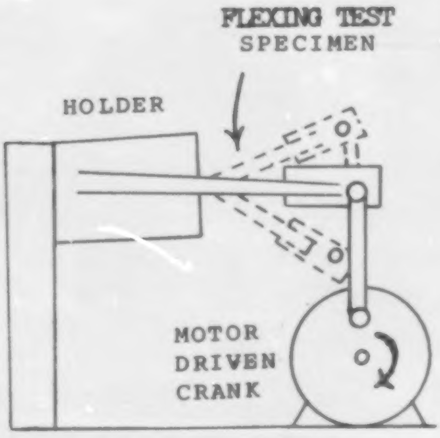
FATIGUE TEST MACHINES

ROTATING SPECIMEN


Compression
Pivot
SPECIMEN
Counter
Motor
Bearing
Bearing
Tension
Stress Load

ROTATION of SPECIMEN

FLEXING SPECIMEN


FLEXING TEST
SPECIMEN
HOLDER
MOTOR
DRIVEN
CRANK

FLEXING OF SPECIMEN

f) Coefficient of Thermal Expansion - Materials change size per unit length (strain) by load applied or by temperature change. The change of length per unit length for each degree of temperature change is called the coefficient of linear thermal expansion.

$$\text{Strain} \quad \varepsilon = \frac{\Delta L}{L} = \alpha \Delta T$$

or

$\Delta L = L\alpha\Delta T$

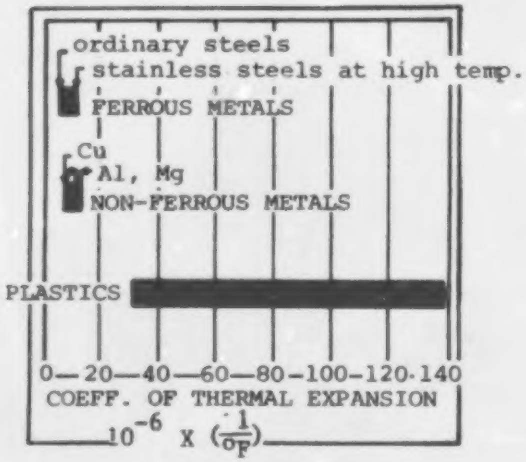
ΔT = Temperature change

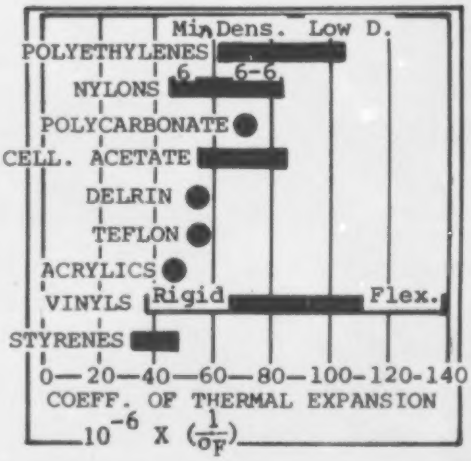
L = Initial part length

α = Coefficient of linear thermal expansion measured in reciprocal degrees ($1/^{o}F$ OR $1/^{o}C$)

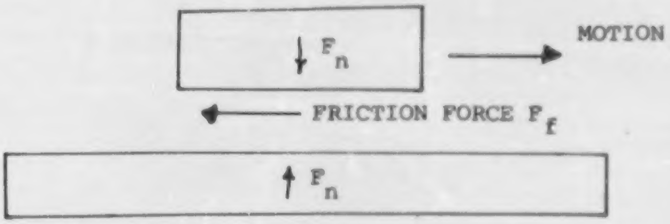
ΔL = Change in length due to temperature change

Values of linear thermal expansion for different fabrication materials are listed below.





g) Coefficient of friction - Two materials in contact with slippage between the two surfaces have drag force produced between the two surfaces which is called the friction force. The friction force is always opposite to the direction of motion. The friction coefficient varies with the relative velocity between the two parts. The friction coefficient between non-moving parts is called static friction coefficient. The friction coefficient between moving parts is called the kinetic, dynamic, or sliding friction coefficient.

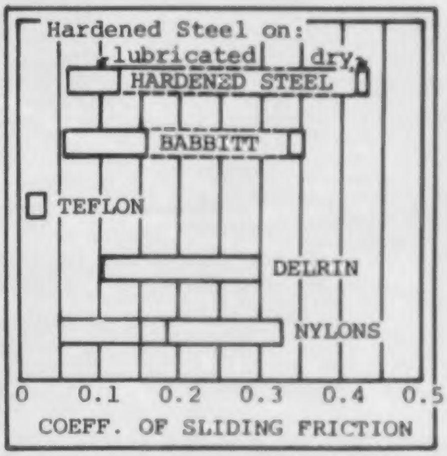


The force between the two surfaces is the normal force F_n.

$$F_f = F_n f$$

f = Friction factor

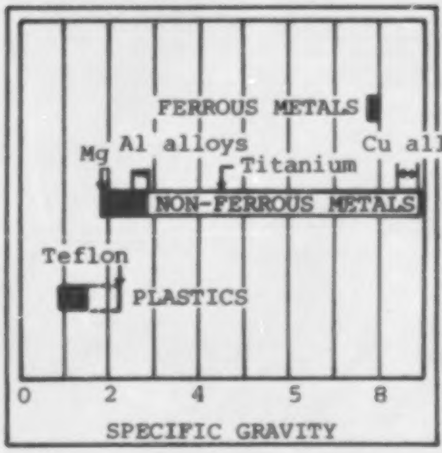
The friction factor includes many variables into one term, such as contact surface area, lubrication, temperature and surface roughness.

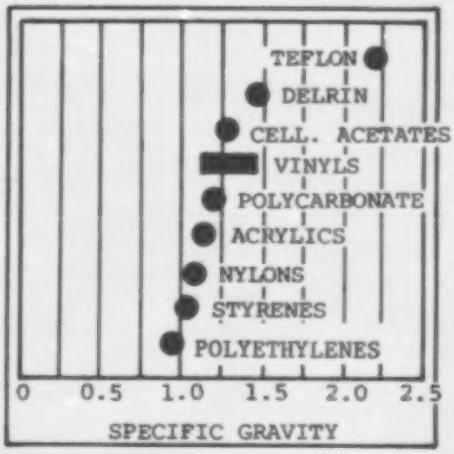


Physical properties include:

a) Specific Gravity - The ratio of the weight of a standard volume of the material to the weight of the same volume of water at 60° F and atmospheric pressure. (It is a dimensionless quantity.)

$$\text{Sp. Gr.} = \frac{\text{wt of material}}{\text{wt of equal volume of water}}$$





b) Thermal Conductivity - Thermal conductivity measures the rate at which heat is transferred through a given cross section area per unit of thickness of the material.

$$Q = k \frac{A}{L} (\Delta T)$$

k = Heat transfer coefficient (Thermal conductivity coefficient)

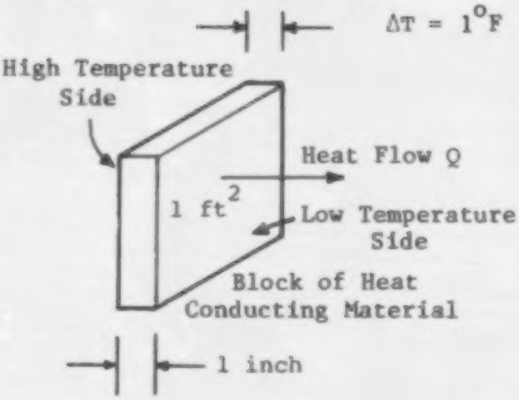
(Btu/h · ft^2 · $^\circ$F/in, in English units)

A = Cross-sectional area (ft^2)

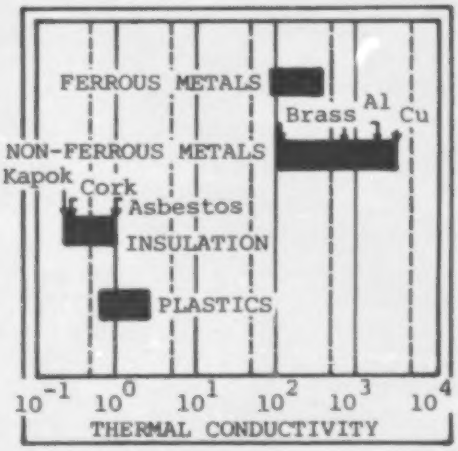
L = Thickness (inches)

ΔT = Temperature difference ($^\circ$F)

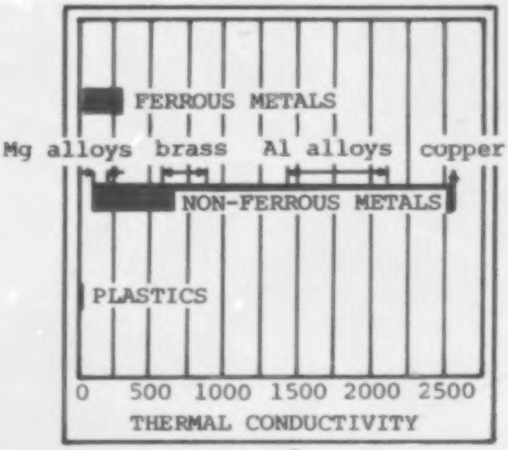
Q = Energy flow rate (Btu /h)



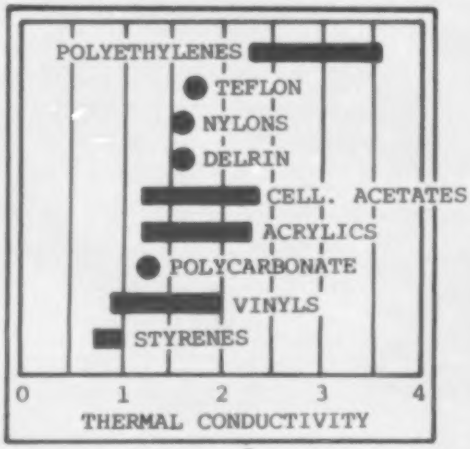
ΔT = 1°F
High Temperature Side
Heat Flow Q
1 ft²
Low Temperature Side
Block of Heat Conducting Material
1 inch



Btu/hr - ft^2 - $^\circ$F/in Logarithmic Scale

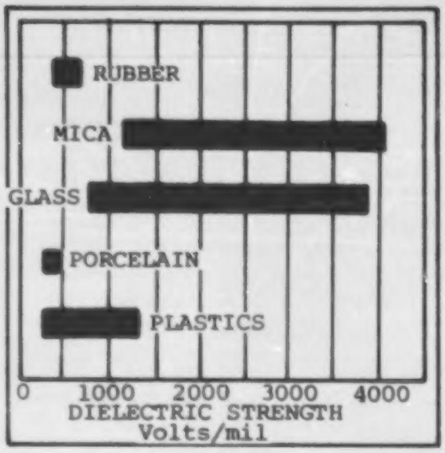


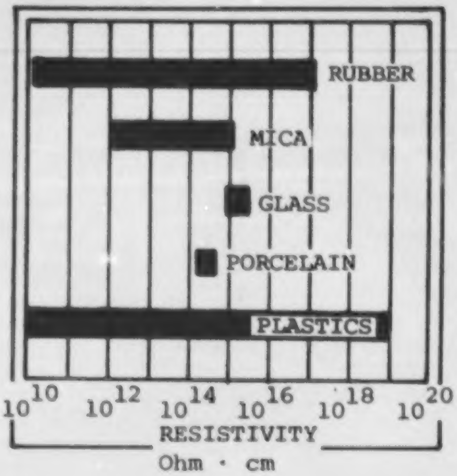
(Btu/h - ft^2 - $^\circ$F/in)



(Btu/h - ft^2 - $^\circ$F/in)

c) Dielectric Strength - The ability of a material to prevent electric current flow at some maximum voltage per mil (1/1000 inch of thickness) of material is called dielectric strength.

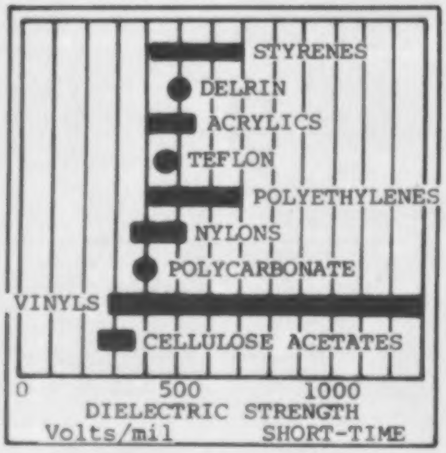


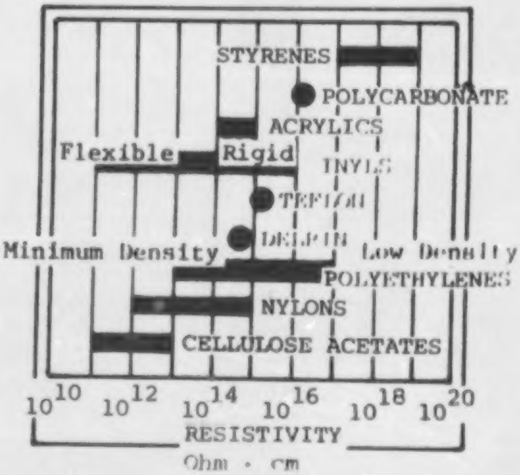


d) Resistivity - Resistivity is the ability of a material to resist electric current flow per unit of thickness.

$$R = \rho \frac{L}{A}$$

R = Resistance in ohms
L = Length of current path
A = Cross section area
ρ = The coefficient of resistivity, a property of the material, given in units of ohm-cm or ohm-in.





LABORATORY SKILLS

The student should have experience in performing the following material property tests:

- Metal tensile test
- Plastic tensile test
- Brittle material tensile test
- Punching shear test
- Impact test
- Bend test
- Compression test

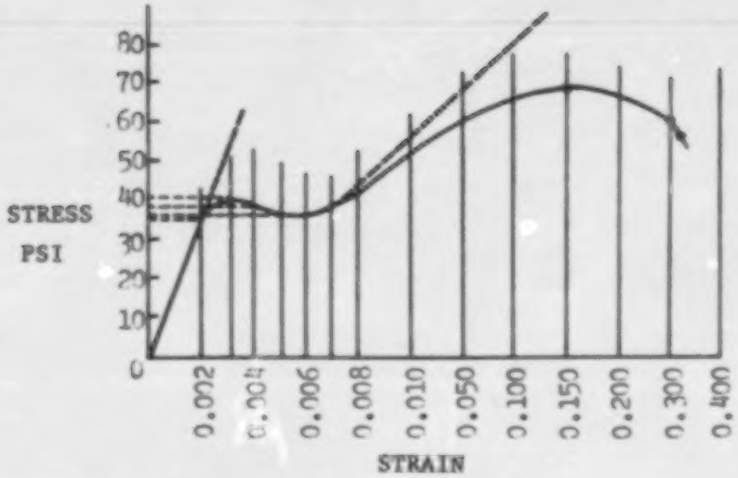
STUDENT PROBLEMS

1. Indicate five mechanical properties tests which may be used to define limits on the use of the materials.

2. A tensile test gives data as follows in the elastic range of the material. What is the modulus of elasticity for this material in lbs/in^2?

Stress (lbs/in^2)	Strain
0	0
2,000	.000066
5,000	.000166
10,000	.000333
15,000	.000501
20,000	.000666

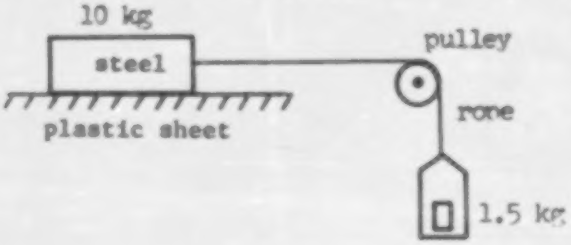
3. A ductile metal is tested and the resulting stress-strain curve is plotted.



Determine the following values:

- a. Yield strength
- b. Ultimate strength
- c. Per cent elongation
- d. Modulus of elasticity

4. A friction test is made with a nylon plastic sheet under a 10 kg block of steel. The horizontal force required to have the block start to slide develops when the mass on the rope is 1.5 kg.



Find:

- a. Coefficient of friction
- b. Force on rope in newtons
- c. Weight of steel block in newtons
- d. Weight of steel block in lbs

Section 2 - Selection and Ordering of Materials

Material selection is a process started by using library reference sources to determine which materials give the properties needed within reasonable cost. After selecting possible materials, literature and accurate cost figures are obtained from suppliers. Delivery time is often critical and may determine which alternate must be used.

Good reference sources include:

Material Properties

A. Materials textbooks
B. Materials engineering selector guide
C. Chemical engineers handbook
D. Hazardous materials book
E. Sales literature from producers
F. ASTM standards
G. ASME and SAE standards

Suppliers

A. Local telephone directory
B. Materials engineering selector guide
C. Thomas register in library
D. Purchasing department of your company

Ordering Materials

Materials should be ordered by specifying:

Material trade name or specification
Number of pieces
Size of pieces
Weight of pieces
Cost per unit weight
or
Cost per unit volume (or unit length)
Color

Cost quotation at point of delivery or point of shipment should be specified. Required specifications should be clearly stated, including standard means for verifying those specs attached to the order.

LABORATORY ACTIVITY AND SKILLS

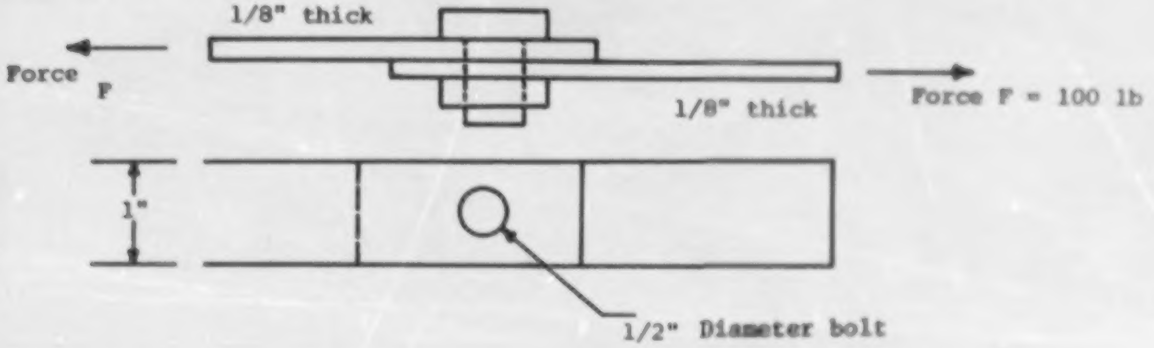
Each student is to prepare a purchase order including supplier.

STUDENT PROBLEMS

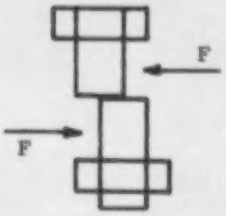
1. List five sources of data to prepare purchase specifications.
2. Indicate four sources of equipment or supplies in your community.
3. List eight important details required for an adequate purchase order.

WORKED EXAMPLE

1. A bolted connection is in tension (see diagram). Determine the stresses in the connection.

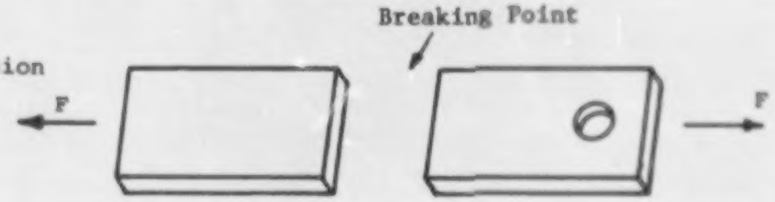

1/8" thick
Force F
1/8" thick
Force F = 100 lb
1"
1/2" Diameter bolt

Bolt in Shear



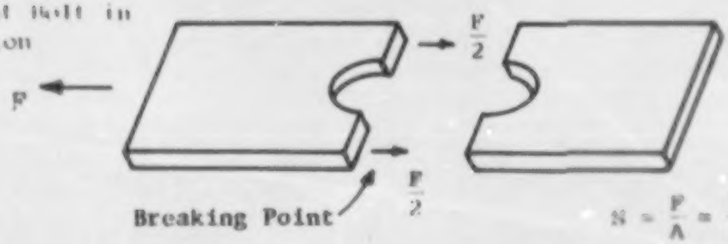
$$S = \frac{F}{A} = \frac{100\ \text{lb}}{\frac{1}{4}\pi\left(\frac{1}{2}\ \text{in}\right)^2} = 500\ \text{lb/in}^2$$

Bar in Tension


Breaking Point
F
F

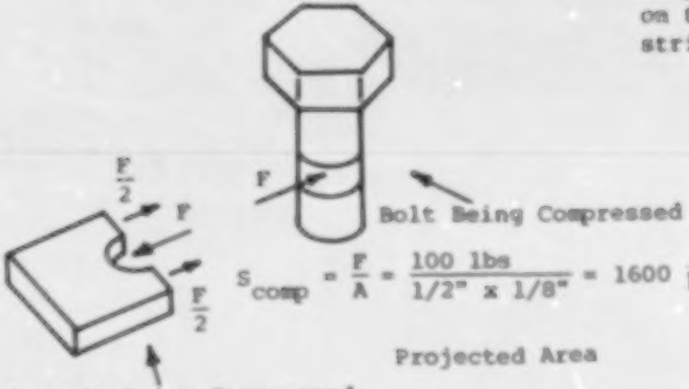
$$S = \frac{F}{A} = \frac{100\ \text{lbs}}{1/8\ \text{in} \times 1\ \text{in}} = 800\ \text{psi}$$

Bar at Bolt in Tension


F
$\frac{F}{2}$
$\frac{F}{2}$
Breaking Point

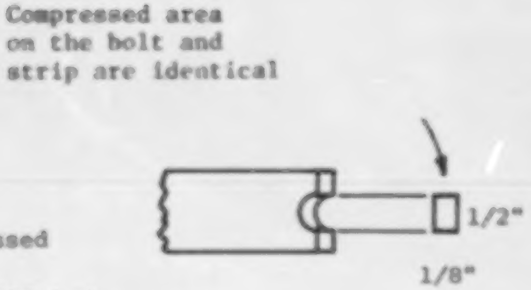
$$S = \frac{F}{A} = \frac{100\ \text{lbs}}{1/4" \times 1/8" \times 2} = 1600\ \text{psi}$$

Bolt in Compression or Load Bearing


F/2
F
F/2
F
Bolt Being Compressed
Metal Strip Being Compressed

$$S_{comp} = \frac{F}{A} = \frac{100 \text{ lbs}}{1/2" \times 1/8"} = 1600 \text{ psi}$$

Projected Area


Compressed area
on the bolt and
strip are identical
1/2"
1/8"

$$S = \frac{F}{A} = \frac{100 \text{ lbs}}{1/2" \times 1/8"} = 1600 \text{ psi}$$

Projected Area of Strip

CHAPTER V

HEAT TREATING

Section 1 - Introduction

Pure metal elements which are ductile can be hardened by three methods:

- A. Strain hardening or work hardening.
- B. Alloying of metal with another metal.
- C. Alloying and heat treating to modify the crystal structure of the metal.

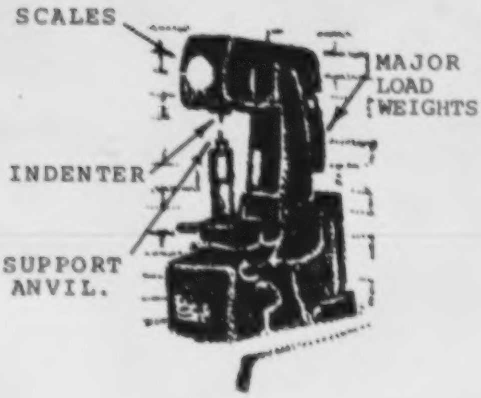
The hardness of a metal is determined by the difficulty of indenting the material or the amount of penetration a hard object will make under controlled loads.

Section 2 - Hardness Testing

Hardness tests are made by comparing a standard material of known hardness to the material being tested. The test methods commonly used are:

A. Rockwell Hardness Test - A brale penetrator or carbide ball of 1/16 inch or 1/8 inch diameter is pressed into a specimen using a small force called a minor load. Then a major load is applied to the penetrator and the depth of penetration is measured on the indicator scale specified. The Rockwell tester is used for laboratory tests or quality control of parts.

It should also be pointed out that one Rockwell number represents 0.000080 in. (0.002 mm) of penetration. Thus, the difference in penetration between a 60 R_c reading and a 65 R_c reading is 0.0004 in.



SCALE RANGES WITH PENETRATOR ARE:

MAJOR MASSES TO PRODUCE LOADS

Scale	Indenter	Mass kg
A	Brale	60
B	1/16" ball	100
C	Brale	150
D	Brale	100
F	1/16" ball	60
G	1/16" ball	150
E	1/8" ball	100 kg

B. Superficial Rockwell Hardness Test - Smaller major loads are used to measure hardness of thin hard materials.

C. Brinell Hardness Test - A 10 mm diameter hardened steel ball, or tungsten carbide ball, is pressed into the surface of the specimen using a 500-kg or 3000-kg mass. The 500-kg mass is used when one is testing soft materials, such as copper or aluminum. The 3000-kg mass is used when one is testing steels and other hard materials. The penetrater is applied for a period of 10 s for 500-kg and 30 s for 3000-kg mass.

The Brinell hardness number (BHN) is the ratio between the load and the surface area of the indentation.

Thus,

$$\text{BHN} = \frac{\text{load mass}}{\text{surface area of indentation}}$$

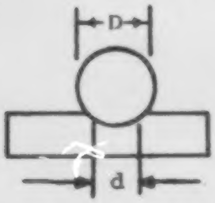
$$= \frac{P}{\frac{\pi D}{2}\left(D - \sqrt{D^2 - d^2}\right)}$$

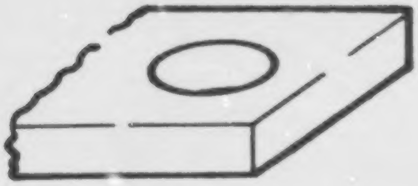
P = load mass, kg

D = diameter of indenter, mm

d = diameter of indentation, mm

BHN = Brinell hardness number





The diameter of the indentation is measured with a scale viewed through a microscope.

The Brinell hardness test value is used extensively to indicate hardness of steel. The tensile strength of steel can be approximated by multiplying the Brinell hardness by 500.

Example:

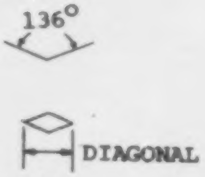
207 BHN x 500 = 103,500 lb/in^2

Published material properties indicate this value 100,000 lb/in^2.

D. Vickers Hardness Test - This operates like the Brinell hardness tester except the diagonal length of the diamond shaped indentation is measured. Loads vary from 5 to 100 kg.

$$DPH = \frac{1.854P}{d^2}$$

DPH = diamond pyramid number
d = diagonal length (mm)
P = mass, kg



Hardness of very small crystals may be individually measured.

E. Tukon Hardness Tester - This tester uses a pyramidal-shaped indenter that has a longitudinal angle of 172.5 deg and a transverse angle of 130°. A square-based diamond indenter with a 136-deg included angle may also be used. Once the indentation is made, the work piece is viewed with a calibrated microscope to measure the long diagonal. This long diagonal is about seven times longer than the short diagonal. The numerical measurement viewed through the microscope may be compared with a chart to determine the hardness number, or it may be obtained from the formula used on small crystals.

The hardness number is used to compare hardness measurements of a known hardness material to the part being tested. The Knoop hardness number is a unit of relative hardness.

$$I = \frac{P}{A} = \frac{P}{\ell^2 C}$$

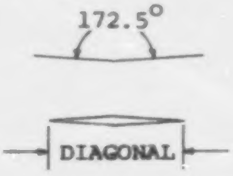
I = noop hardness number

P = load, kg

A = projected area of indentation, mm^2

ℓ = length of long diagonal, mm

C = constant



F. Shore Sclero Scope Hardness Tester - A hard penetrator is dropped on the material surface and the height of rebound is measured. The harder the material, the more elastic the collision and the higher the rebound.

G. Durometer Hardness Test - This is used to test rubber or elastomeric materials. The depth a penetrator will indent the rubber is the indicated hardness.

Section 3 - Strain Hardening and Annealing

Strain hardening takes place in a metal when it is rolled or deformed below its recrystallization temperature.

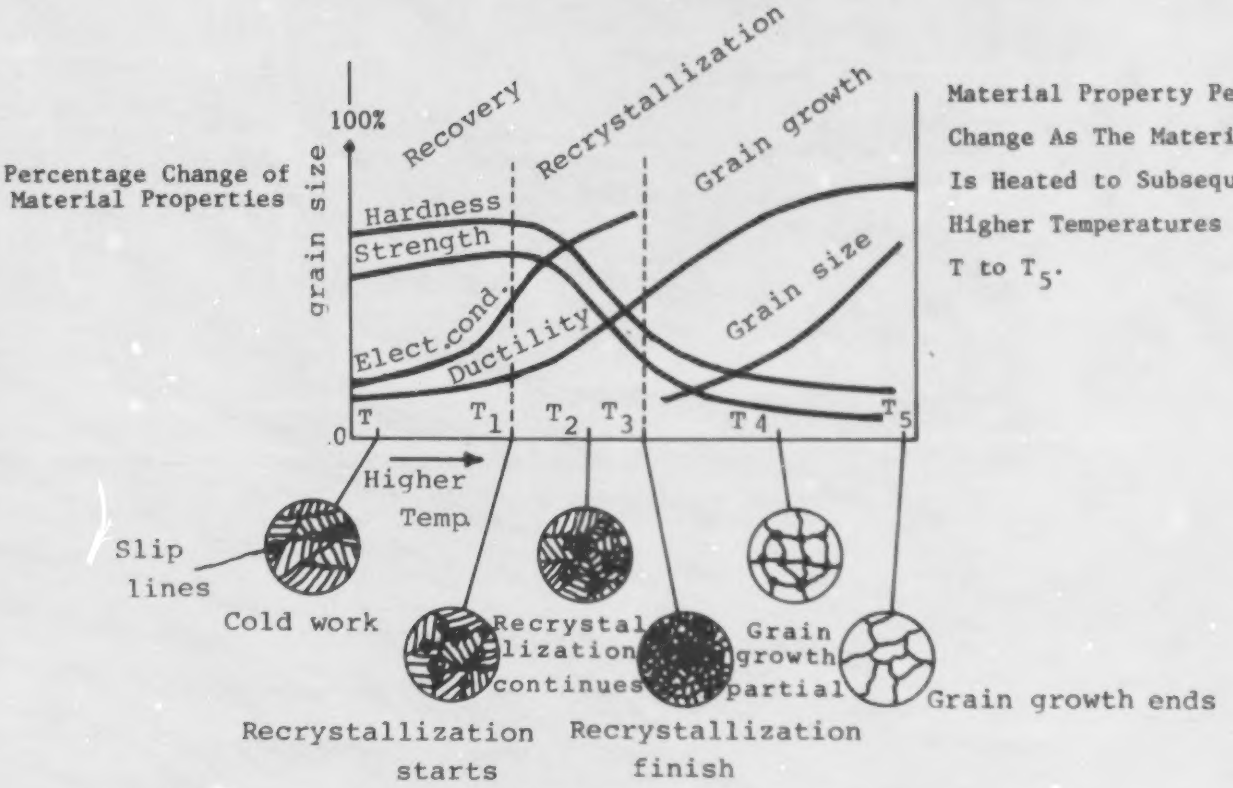
METAL RECRYSTALLIZATION TEMPERATURES

Metal	Recrystallization Temperature (^{o}F)	Metal	Recrystallization Temperature (^{o}F)
Aluminum	300	Molybdenum	1655
Beryllium	1300	Nickel	1115
Cadmium	75	Platinum	850
Copper	390	Silver	390
Gold	390	Tin	65
Iron	850	Tantalum	1830
Lead	65	Titanium	1220
Magnesium	300	Zinc	75

Metals upon cooling from a liquid, form many metal single crystals which make up the composite material piece we use. The crystals are found to regrow into new crystals upon heating to the recrystallization temperature.

The process of strain hardening is thought to be due to the fact that ductile metals have many planes of atoms which slip or deform (twinning) and allow the metal to change shape. As more deformation and slipping of the atoms take place, the number of planes which can move is reduced. This process is called strain hardening or work hardening. Low temperature will allow strain hardening in metals. Tin and lead must be at temperatures below 65° F to work harden.

Annealing - Metals may have their crystal structure changed by heating the metal above the recrystallization temperature for a period of time. The formation of new crystals increases the number of slip planes of atoms, making the material softer and more ductile. Over-heating causes a large, coarse crystal structure. The heating and subsequent slow cooling of a metal is called annealing.



Material Property Percent Change As The Material Is Heated to Subsequently Higher Temperatures From T to T_5.

Section 4 - Alloying and Crystal Structure

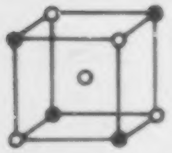
Metals may be hardened by adding an additional element to the molten metal. This is a type of alloying, the process of mixing metals. The added element is called the solute. The molten metal is the solvent. The size of the atom of the element added determines whether the alloying element replaces one of the metal atoms in the crystal structure (substitutional solid solution), or the element falls between the crystal atoms (interstitial solid solution).

LABORATORY ACTIVITY AND SKILLS

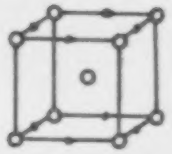
Students should strain harden ductile metals using rolling, stretching, or bending operations. Annealing and normalizing should be done with hardness and/or tensile testing afterward.

When possible, metallographic specimens should be made to compare crystal structure.

CRYSTALS OF ALLOYS

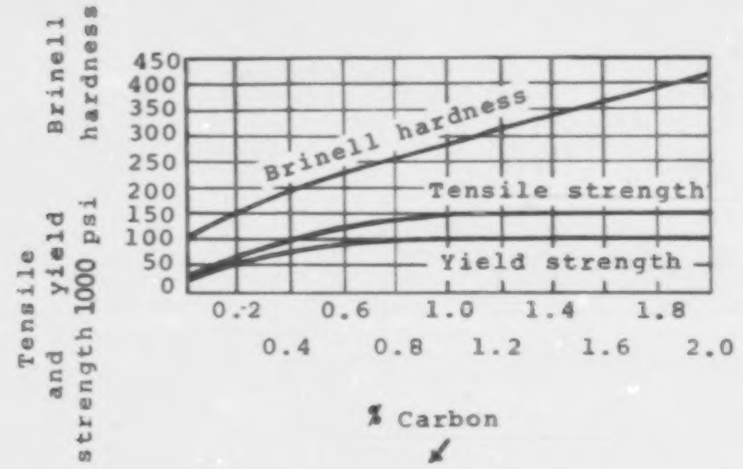


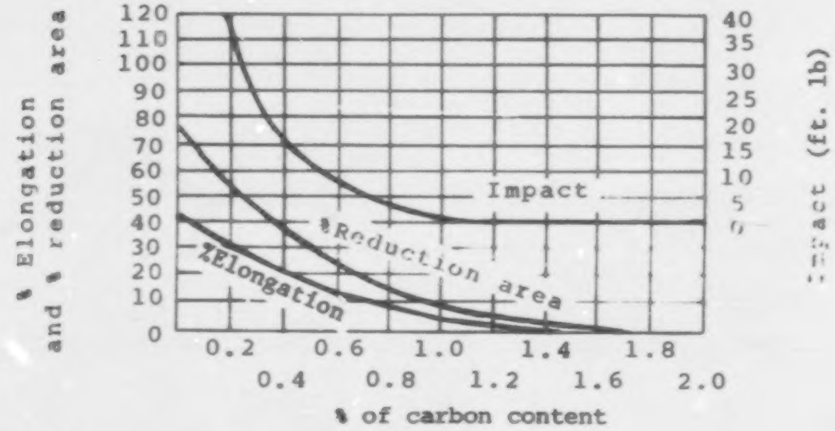
SUBSTITUTIONAL SOLID SOLUTION



INTERSTITIAL SOLID SOLUTION

The result of alloying carbon with pure iron is shown below.





Many metals may be mixed together to develop different physical and chemical properties.

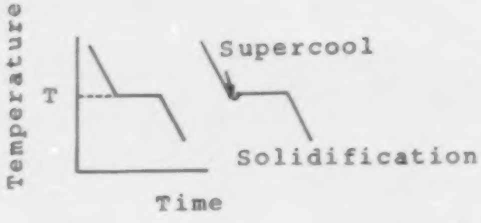
The mixing of two or more elements into a solid mixture (of varying proportions) is an alloy where the combined elements have properties of one material. The combined elements exhibiting a unique set of physical properties is called a phase. Phase changes of a two element mixture may result from:

Alloy solidifying from a liquid to a single phase solid.
Pure metal solidifying from a liquid.
An alloy liquid changing to a two phase liquid (the metals do not alloy).
An alloy liquid changing to a liquid phase and a solid phase.
An alloy liquid changing to a two phase solid.
A single phase alloy changing to a two phase alloy.

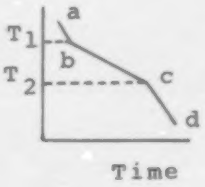
Physical phase changes are often determined by:

Measuring mechanical properties.
Examining crystal structure.
Checking magnetic properties.
Looking at the slow cooling of a material on a temperature versus time curve.

A phase is a part of an alloy that does not require chemical methods to make the part distinguishable. Pure metals are found to remain at constant temperature while a single phase change takes place in crystal structure. When two elements are alloyed, the slope of the cooling curve changes and the temperature does not remain constant. (See figures below.)



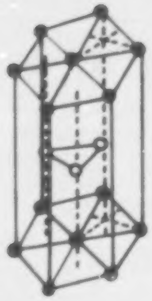
Pure Metal
During
Solidification

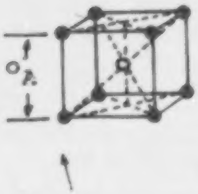


Two Phases Present
During Cooling.

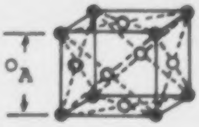
As a pure molten metal cools to the solidification temperature, the atoms drop into an ordered array called a crystal. The random movement of the molten metal atoms results in variations in time for the crystallization to begin and also in the plane where the crystal structures may start forming. The cooling in the casting of metals results in the material being composed of many small crystals called grains. The intersection of each small grain is a grain boundary.

Ductile metals are found to have different crystal structures dependent on metal temperature, alloying elements present, and the heat treatment of the metal. The common crystal structures found in metals are shown below.





^{o}A = Angstrom units = 10^{-10}m



Hexagonal Close Packed
(CPH)

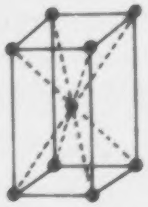
Beryllium
Cadmium
Cobalt
Magnesium
Titanium
Zinc
Zirconium

Body-Centered
Cubic (BCC)

Iron (Alpha + Delta)
Tungsten
Chromium
Vanadium
Molybdenum
Cesium

Face-Centered
Cubic (FCC)

Iron (Gamma)
Aluminum
Copper
Gold
Lead
Nickel
Platinum
Silver



Body Centered Tetragonal (BCT)

Iron (Heat treated to form Martensite)

As the temperature of metals are changed they may change crystal structure. Examples are:

Chromium: close-packed hexagonal, below 68° F
body-centered cubic, 68 to 3270°F

Cobalt: close-packed hexagonal, below 788°F
face-centered cubic, 788 to 2723°F

Iron: body-centered (α) cubic, below 1670°F
face-centered (γ) cubic, 1670 to 2552°F
body-centered (δ) cubic, 2552 to 2795°F

Manganese: cubic (α) below 1252°F
cubic (β) 1252 to 2012°F
tetragonal (γ), 2012 to 2080°F
tetragonal (δ) 2080 to 2273°F

Tin: cubic (α), below 55.8°F
tetragonal (β), 55.8 to 450°F

Titanium: close-packed hexagonal, below 1615°F
body-centered cubic, 1615 to 3140°F

Heat treating is another means of changing the hardness, strength, and ductility of metal alloys. The effect of heat treating ferrous and non-ferrous alloys is quite different so each will be covered separately in the next sections.

LABORATORY ACTIVITY AND SKILLS

The students should alloy metals or run cooling curve tests on different metal alloys. Cooling curve results should be compared with published figures.

Section 5 - Quench Hardening of Ferrous Metals

Ferrous metals are hardened by changing the crystal structure. The hardness is controlled by controlling the amount of martensite in the crystal structure. Martensite has a body centered tetragonal crystal structure, which forms when face centered cubic iron, called austenite, is cooled quickly by quenching.

The martensite formation is controlled by the carbon alloy present, by how fast metal is cooled (cooling rate), by other alloying elements which restrict changes of crystal structure, and by the size and temperature of the parts to be quenched. Austenite must be present before quenching to obtain hardening.

The number of alloys and cooling conditions give so many parameters to consider that we must select test methods which group the many parameters into a few important ones.

Alloy parameters to be measured:

A. Temperature required to obtain face centered cubic austenite

B. Carbon content

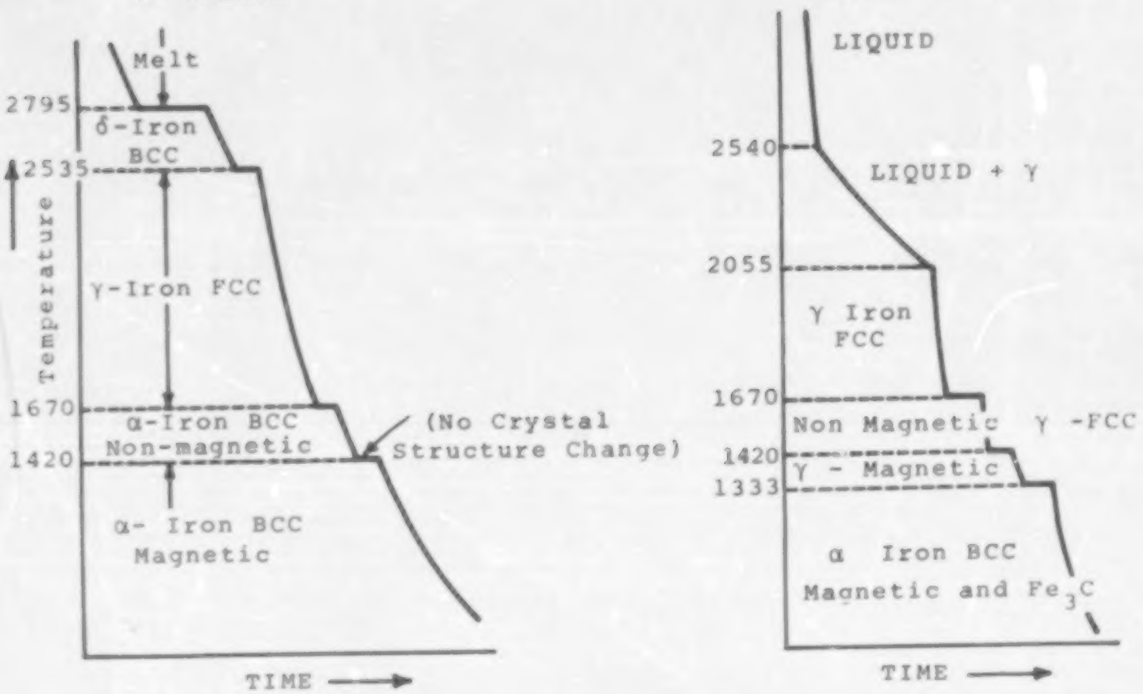
C. Quench rate or cooling rate

D. Hardness achievable

E. Depth of hardening

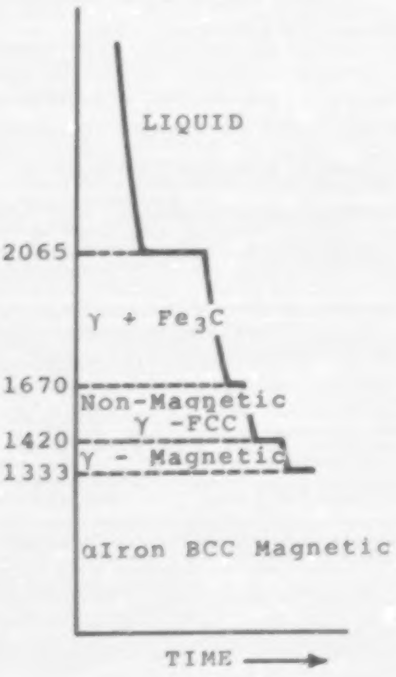
The temperature required for the carbon content present is measured using a Phase Equilibrium Diagram. The diagram is developed from a number of slow cooling curves for iron with different carbon compositions. See curves below.

A set of three of the many possible iron carbon cooling curves.

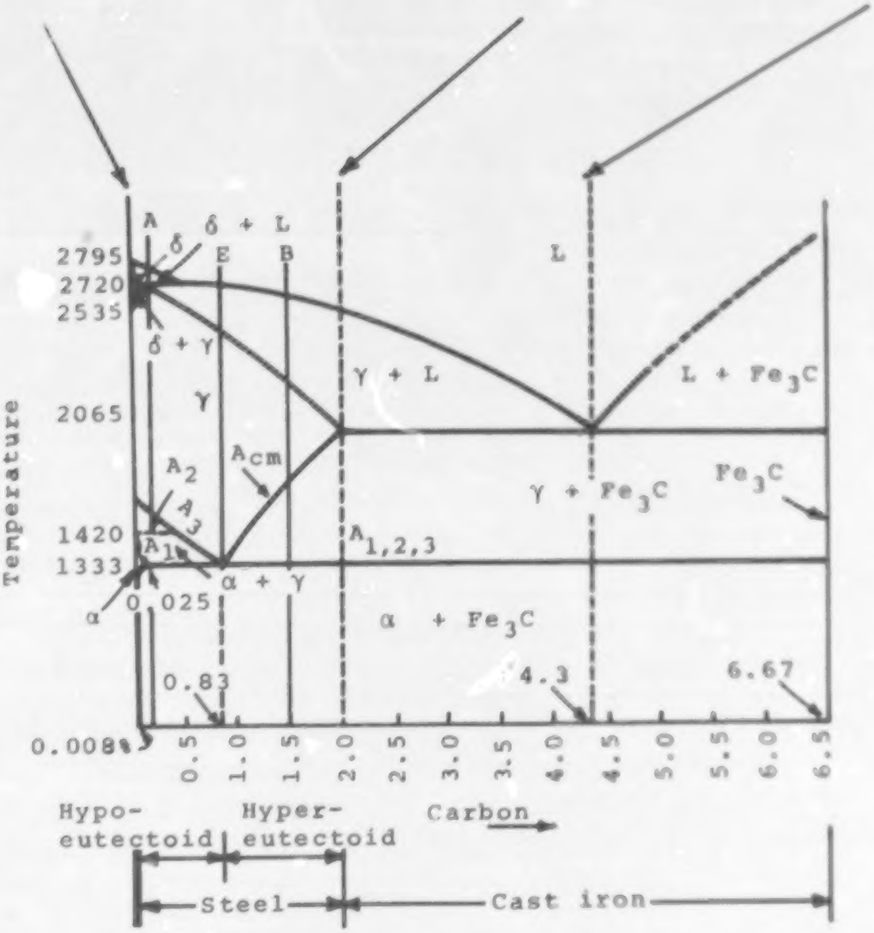

0% Carbon

2.0% Carbon

4.3% Carbon



The cooling curves shown on the previous page show the phase changes for each alloy content of carbon indicated by the arrows.


A
δ + L
δ
E
B
L
2795
2720
2535
δ + γ
γ + L
L + Fe3C
γ
2065
Temperature
A2
Acm
γ + Fe3C
Fe3C
A3
1420
A1
A1,2,3
1333
α + γ
α
0.025
α + Fe3C
0.83
4.3
6.67
0.008%
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
Hypo-eutectoid
Hyper-eutectoid
Carbon
Steel
Cast iron

PHASE EQUILIBRIUM DIAGRAM (IRON + CARBON)

Using the phase equilibrium diagram for the alloy iron being used and knowing the carbon content and temperature we find the phase present. Each alloy present shown on the phase equilibrium diagram is listed below.

L - Liquid - Molten iron and carbon interstitial alloy

δ - Delta - Body centered cubic iron - 2535°F to 2795°F

$\delta + L$ - Mixture of liquid phase and a solid phase

γ - Gamma - Face centered cubic iron. Carbon and iron alloy of Gamma iron is called Austenite. Can dissolve large amount of carbon. Soft and ductile.

$\gamma + L$ - Two phase mixture of γ and liquid

$\gamma + \delta$ - Two phase mixture of γ and δ iron

Fe_3C - Iron Carbide or Cementite - Hardest and most brittle component of steel Composed of 6.67% carbon.

At 6.67% carbon all of the iron alloy forms into iron carbide.

$Fe_3C + L$ - Two phase mixture - Solid phase of iron carbide and liquid phase of molten iron and carbon.

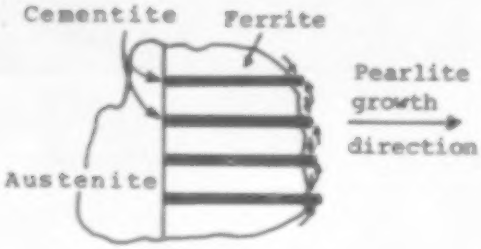
$\gamma + Fe_3C$ - Two phase mixture - Solid phase of γ iron and solid phase of iron carbide mixed.

α - Alpha - Body centered cubic iron - Softest component of steel. Very ductile.

Special structures of iron and carbon alloys form when enough carbon is present.

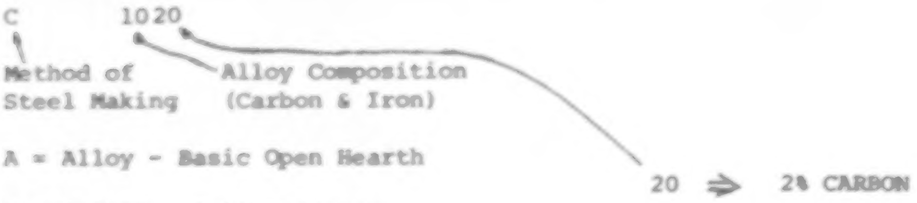
Pearlite - .83% carbon - strong (115,000 PSI.)
10% elongation in 2 inches.

Ledebrite - Forms with over 2% carbon - contains 4.3% carbon in combination with iron. Less ductile than pearlite.


Cementite
Ferrite
Pearlite growth direction
Austenite

Steel alloys are made in select alloy compositions which give the needed range of material properties with adequate quality control of the properties.

The American Iron and Steel Institute specifies steel by a letter and a four digit number. Omitting the letter indicates open hearth steel.


C
1020
Method of Steel Making
Alloy Composition (Carbon & Iron)
20 ⇒ 2% CARBON

A = Alloy - Basic Open Hearth

B = Carbon - Acid Bessemer

C = Carbon - Basic - Open Hearth

D = Carbon - Acid - Open Hearth

E = Electric Furnace

AISI Steels

Classification	Number	Range of Numbers
Carbon steel SAE-AISI	1XXX	
Plain carbon	10XX	1006-1095
Free machining (resulphurized)	11XX	1108-1151
Resulphurized, rephosphorized	12XX	1211-1214
Manganese (1.75 per cent Mn)	13XX	1320-1340
Nickel	2XXX	
3.5% Ni	23XX	2317-2345
5.0% Ni	25XX	2512-2517
Nickel-Chromium	3XXX	
1.25% Ni, 0.65% Cr	31XX	3115-3150
1.75% Ni, 1.00% Cr	32XX	
3.50% Ni, 1.55% Cr	33XX	3310-3316
Corrosion-resist, stainless	30XX	
Austenitic stainless	303XX (AISI 300 series)	
Molybdenum	4XXX	
C-Mo (0.25% Mo)	40XX	4024-4068
Cr-Mo (Cr, 0.70%; Mo, 0.15%)	41XX	4130-4150
Ni-Cr-Mo(Ni 1.8%, Cr 0.65%)	43XX	4317-4340
Ni-Mo (1.75% Ni)	46XX	4608-4640
Ni-Cr (0.45%)-Mo (0.2%)	47XX	
Ni-Mo (3.5% Ni, 0.25% Mo)	48XX	4812-4820
Chromium	5XXX	
0.5% Cr	50XX	
1.0% Cr	51XX	5120-5152
1.5% Cr	52XXX	52095-52101
Corrosion-heat resistant	514XX	(AISI 400 series)
Chromium-Vanadium	6XXX	
1% Cr.-0.12V,	61XX	6120-6152
Silicon-Manganese		
0.85 Mn, 2% Si	92XX	9255-9262
Triple-alloy steels		
0.55% Ni, 0.50% Cr, 0.20% Mo	86XX	8615-8660
0.55% Ni, 0.50% Cr, 0.25% Mo	87XX	8720-8750
3.25% Ni, 1.20% Cr, 0.12% Mo	93XX	9310-9317
0.45% Ni, 0.40% Cr, 0.12% Mo	94XX	9437-9445
0.45% Ni, 0.15% Cr, 0.20% Mo	97XX	9747-9763
1.00% Ni, 0.80% Cr, 0.25% Mo	98XX	9840-9850
Boron (about 0.005% (Mn))	XXBXX	

Boron is denoted by addition of B. Boron-Vanadium is denoted by the addition of BV. Examples: 14BXX, 80BXX, 43BV14.

TS denotes "tentative standard"; TS4150.

Stainless steels are a classification of high chromium and/or nickel steels which exhibit good corrosion and oxidation resistance.

Classification and uses of the "stainless" steels.

	AISI Type	Usage
Martensitic	410	General purpose
(Hardenable by heat	420	
treatment)	440C	
Chromium + Carbon		Heat treatable
11.5-18.% .2-1.2%		
Ferritic	405	
(More corrosion resistant	430	
than martensitic, but can-	446	
not be hardened by heat		Cold working will increase
treatment)		hardness
Chromium + Iron		
11.5 - 28%		
Low carbon		
Less than .35%		
Austenitic	201	For elevated temperature
(Best corrosion resistance	202	service
but can only be hardened by	301	
by cold working)	302	
Nickel, Chromium + Iron		
8% , 16-26%		
Non-magnetic	302B	Modified for welding
	304L	
200 Series - Manganese	310	
Replaces Nickel	316	Superior corrosion
	321	resistance
300 Series - Nickel		

COMPOSITION OF THE STAINLESS STEEL ALLOYS

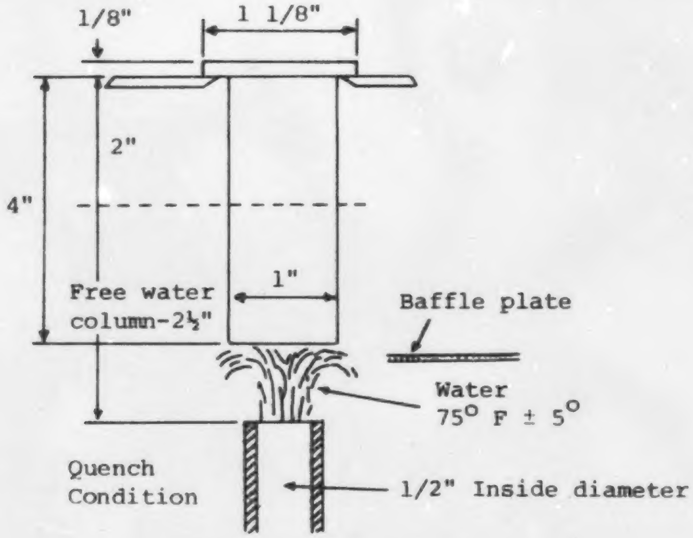
Alloy	%C	%Cr	%Ni	Other
301	0.15	16.0-18.0	6.0-8.0	2.00% Mn, 1.00% Si
302	0.15	17.0-19.0	8.0-10.0	2.00% Mn, 1.00% Si
303	0.15	17.0-19.0	8.0-10.0	2.00% Mn, 1.00% Si, 0.15% S(min)
304	0.08	18.0-20.0	8.0-12.0	2.00% Mn, 1.00% Si
304L	0.03	18.0-20.0	8.0-12.0	2.00% Mn, 1.00% Si
305	0.12	17.0-19.0	10.0-13.0	2.00%Mn, 1.00% Si
308	0.08	19.0-21.0	10.0-12.0	2.00%Mn, 1.00% Si
316	0.08	16.0-18.0	10.0-14.0	2.00%Mn, 1.00% Si, 2-3% Mo
321	0.08	17.0-19.0	9.0-12.0	2.00%Mn, 1.00% Si,0.4% Ti (min)
347	0.08	17.0-19.0	9.0-13.0	2.00%Mn, 1.00% Si 0.8% Cb (min)
410	0.15	11.5-13.5	--	1.00%Mn, 1.00% Si
416	0.15	12.0-14.0	--	1.25%Mn, 1.00% Si, 0.15%S(min)
416Se	0.15	12.0-14.0	--	1.25%Mn, 1.00% Si,0.15% Se
420	0.15	12.0-14.0	--	1.00%Mn, 1.00% Si
440	0.60	16.0-18.0	--	1.00%Mn, 1.00% Si, 0175% Mo
430	0.12	14.0-18.0	--	1.00%Mn, 1.00% Si

The quench rate, hardness and depth of hardness is controlled using the standard Jominy Test. Shown below a 1 inch diameter steel specimen is water cooled on one end. The rate of cooling varies along the bar as does the hardness achieved.

Quench Rate H-Value	Quench Conditions*	Agitation
0.20	poor oil quench	none
0.35	good oil quench	moderate
0.50	very good oil quench	good
0.70	strong oil quench	violent
1.00	poor water quench	none
1.50	very good water quench	strong
2.00	brine quench	none
5.00	brine quench	violent
∞	ideal quench	

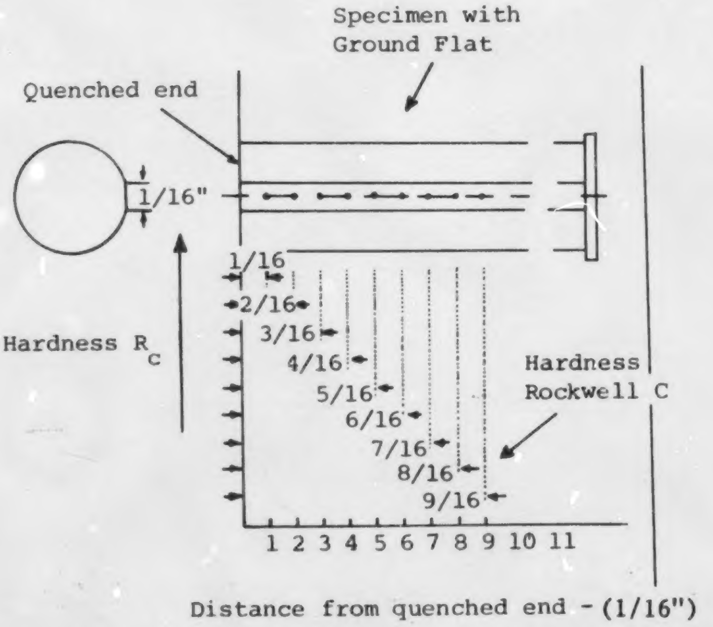
*United States Steel, Carilloy Steel. Published by Carnegie-Illinois Steel Corp., Pittsburgh, Penn. (1948), p. 42.

Standard Jominy Test


1/8"
1 1/8"
2"
4"
1"
Free water column-2½"
Baffle plate
Water
75° F ± 5°
Quench Condition
1/2" Inside diameter

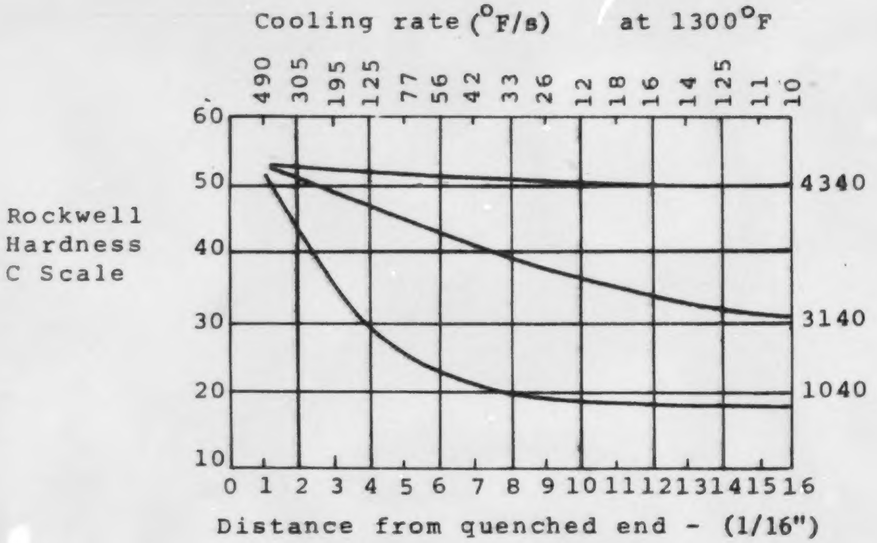
Distance from quenched end, (in)	cooling rate (°F/s) at 1300°F
1/16	489
1/8	307
3/16	195
1/4	124
5/16	77.2
3/8	56.3
7/16	41.9
1/2	32.3
9/16	25.0
5/8	21.4
11/16	19.5
3/4	16.3
13/16	14.5
7/8	12.4
15/16	11.5
1	10.0
1 1/4	7.0
1 1/2	5.1
1 3/4	4.0
2	3.5

*From United Steel, Carilloy Steel. Published by Carnegie-Illinois Steel Corp., Pittsburgh, Penn. (1948), p. 41.


Specimen with Ground Flat
Quenched end
1/16"
1/16
2/16
3/16
4/16
5/16
6/16
7/16
8/16
9/16
Hardness R_C
Hardness Rockwell C
1 2 3 4 5 6 7 8 9 10 11
Distance from quenched end - (1/16")

Jominy test results for each alloy indicate hardness and depth of hardness for the cooling rate at each 1/16 inch interval.

Depth of hardness is controlled by alloys other than carbon. Hardenability is the indication of depth of hardness.

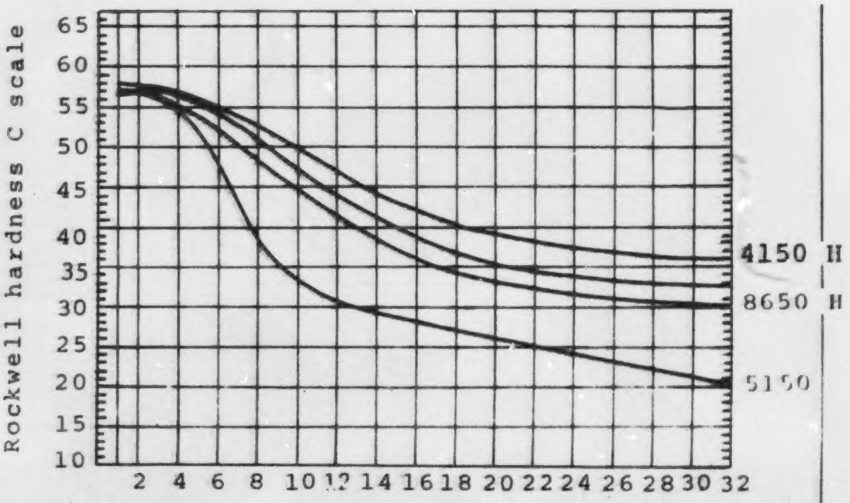


Constant Carbo
Content .4%

High Alloy
Good Depth of
Hardening

Low Alloy
Poor Depth
of Hardening

Constant Carbo
Content .5%



Chromium +
Molybdenum

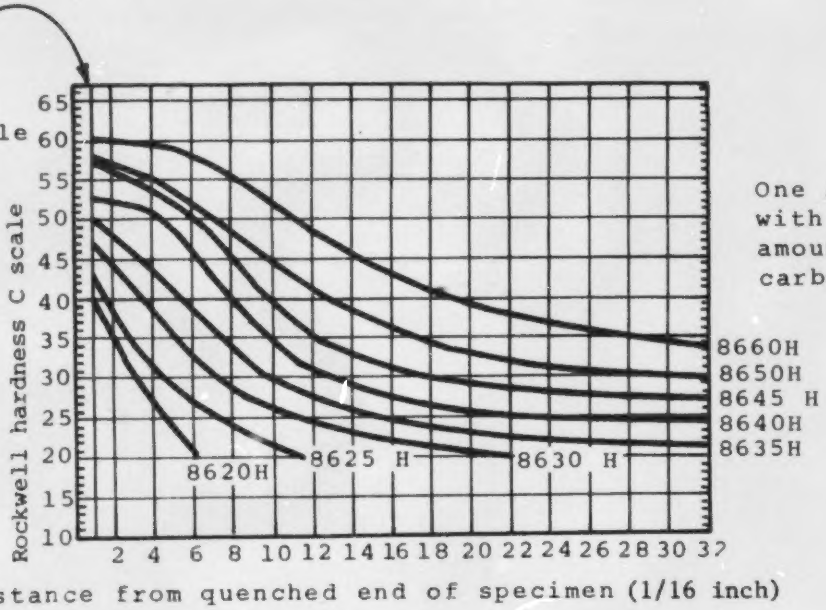
Nickel, Chromi
+ Molybdenum

Chromium Only

Distance from quenched end of specimen in sixteenths of an inch.

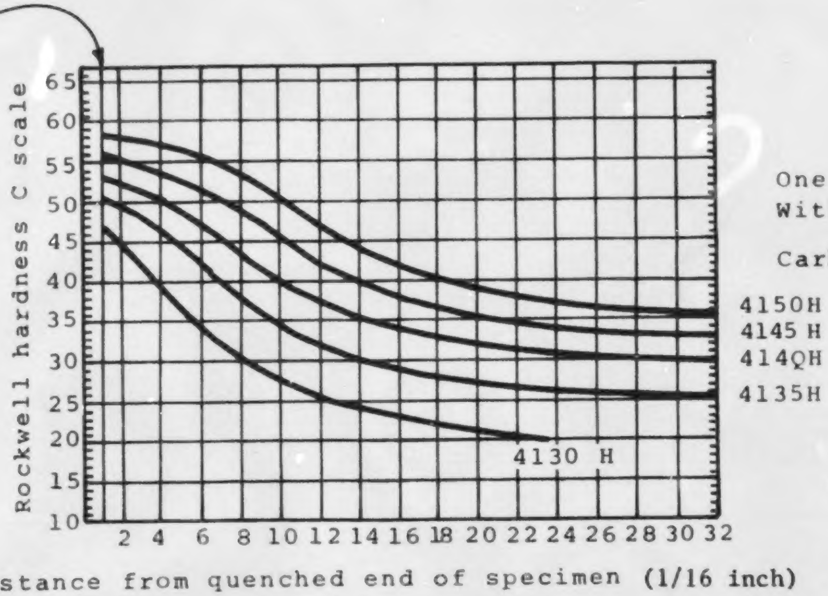
Maximum hardness is dependent on carbon content.

Maximum
Hardness
Obtainable
By
Water
Quench



One Alloy
with varying
amounts of
carbon.

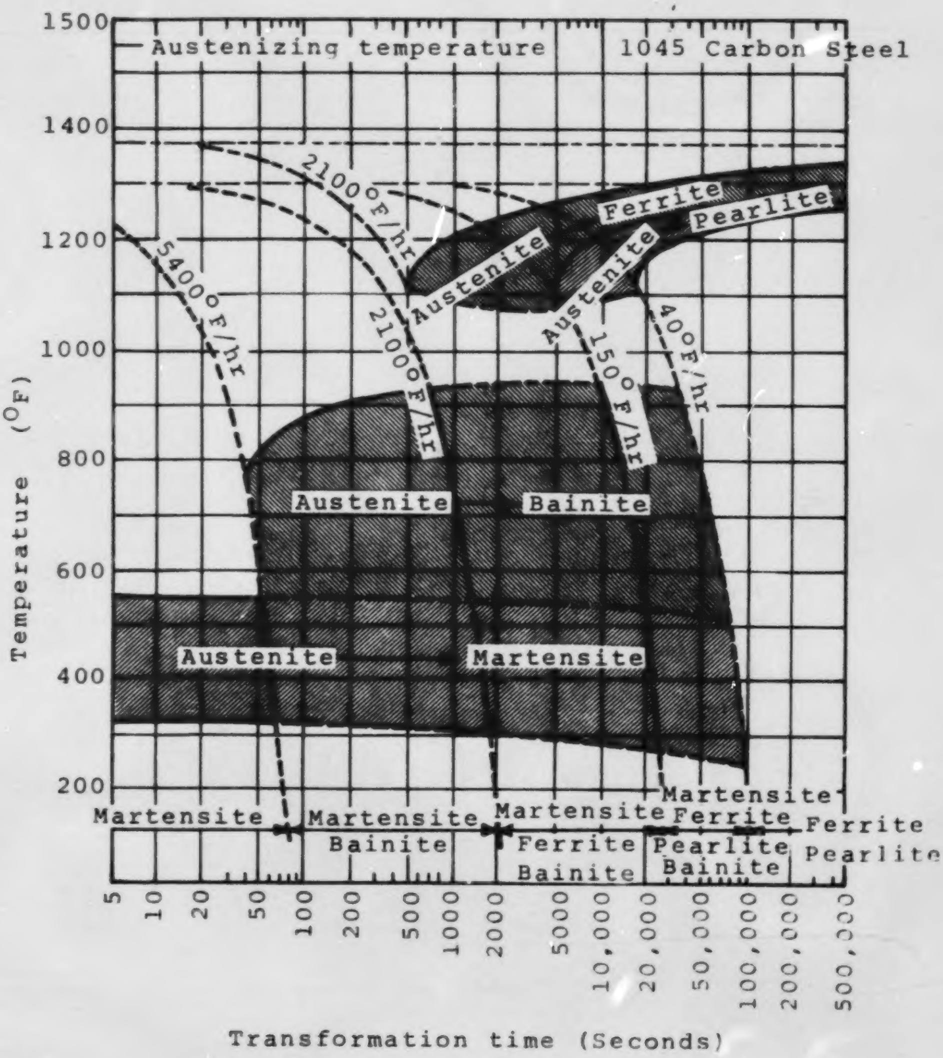
Maximum
Hardness
With
Water
Quench



One Alloy
With Varying

Carbon.

Quench hardening produces variations in hardness due to the cooling rate differences in regions of an intricate part. The metal surface and the thin sections cool most rapidly. A plot of temperature versus time showing the cooling rates for crystal transformation can be used to control hardness.

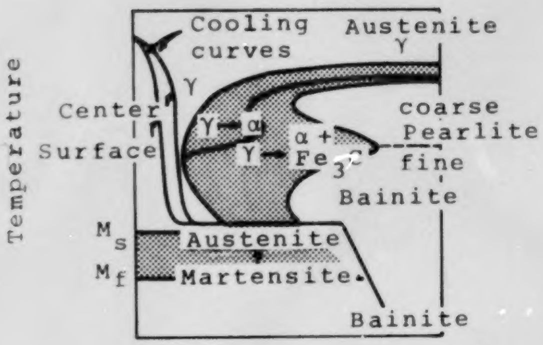


Bainite is a modified martensite crystal structure which is more ductile but retains high strength.

Two methods of controlling hardness are austempering and martempering. Austempering results in less violent temperature change and less martensite formation. Reduced warpage, internal stresses, and cracking of the part result.

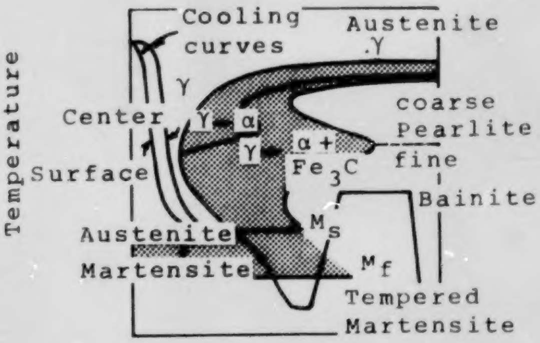
Martempering requires sudden cooling to produce a martensite crystal structure and then reheating to balance martensite to bainite formation. The martensite alone being too brittle for engineering materials.

Austemper



Cooling curves
Austenite
γ
Center
Surface
γ
γ→α
α +
γ→Fe₃C
coarse
Pearlite
fine
Bainite
Temperature
M_s
Austenite
M_f
Martensite
Bainite

Martemper

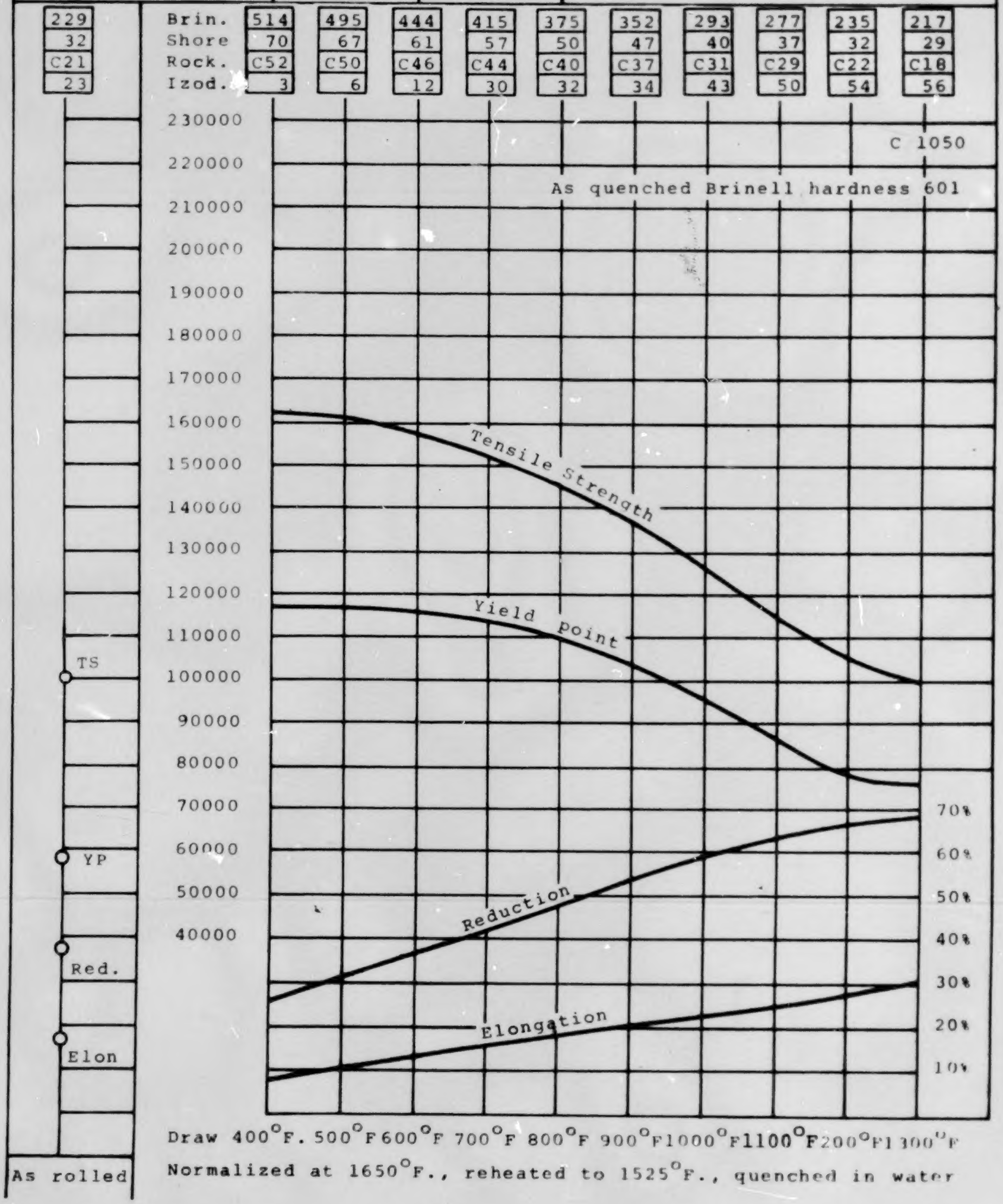


Cooling curves
Austenite
γ
Center
Surface
γ
γ→α
α +
γ→Fe₃C
coarse
Pearlite
fine
Bainite
Temperature
Austenite
M_s
Martensite
M_f
Tempered Martensite

A more even hardness throughout the part results by austempering because the material temperature is held more constant. Martempering results in very hard surfaces with more brittle martensite present. Brittleness is reduced by reheating the martensite so more ductile bainite is formed. The process is called tempering. The reheat temperature is the draw temperature which causes a drawing out of the brittleness. The effect of draw temperature on a martempered specimen of C1050 and 3140 steel is shown below.

C 1050 CARBON STEEL

1" Rd. Size treated 505" Rd. Size tested	Ac_1 1340°F Ac_3 1420°F	Ar_3 1320°F Ar_1 1250°F	C .48/.55 Mn. .60/.90 P. Max. .04 S. Max. .05



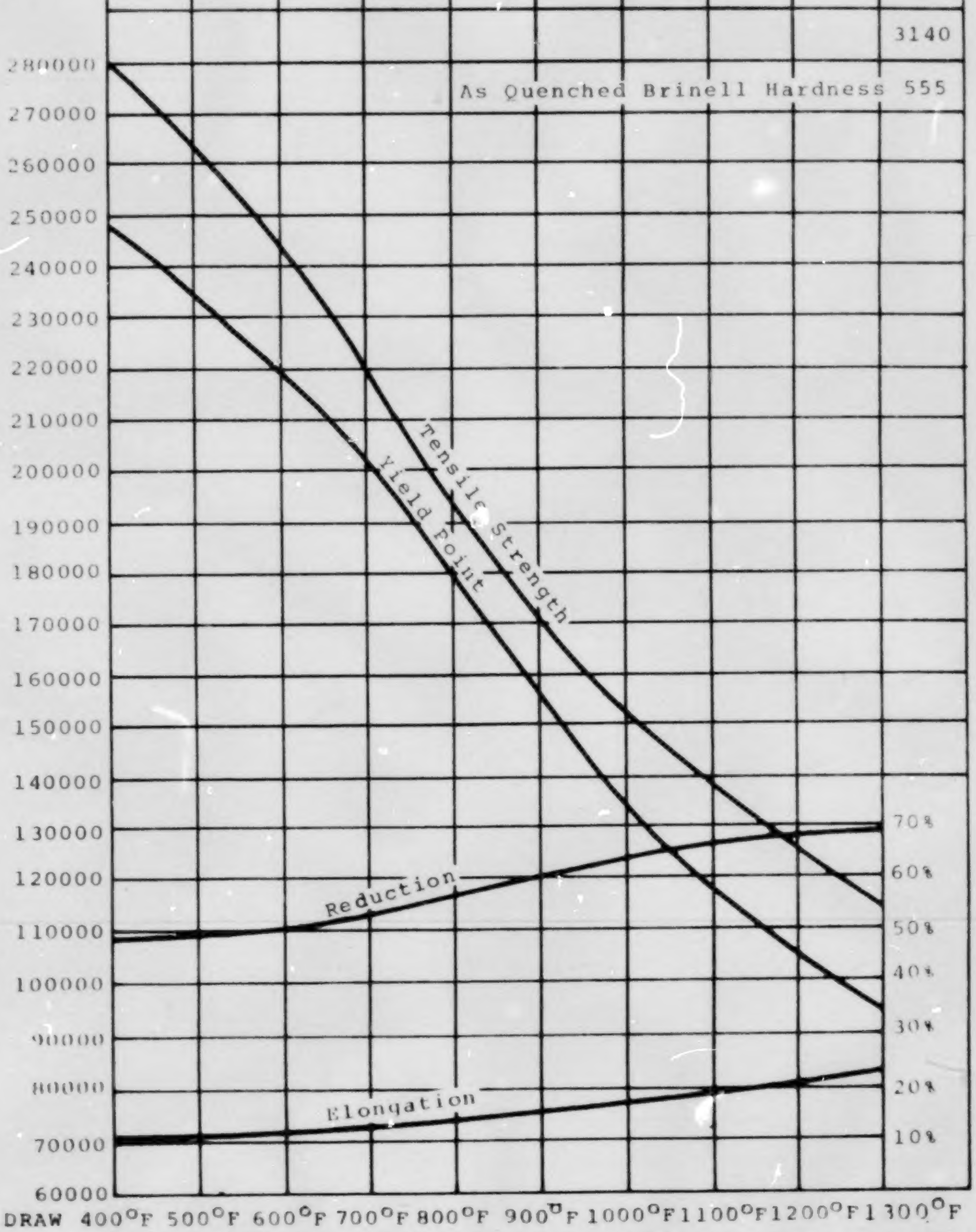
Draw 400°F. 500°F 600°F 700°F 800°F 900°F 1000°F 1100°F 1200°F 1300°F

Normalized at 1650°F., reheated to 1525°F., quenched in water

3140
NICKEL-CHROMIUM-CARBON STEEL

500 Rd. SIZE TREATED 505 Rd. SIZE TESTED	Ac_1 1360°F Ac_3 1420°F	Ar_3 1265°F Ar_1 1200°F	C	Mn	P	S	Si	Ni		Mo	Grain Size
			38/43	70/90	Min 04	Max 04	20/35	10/1 40			
HEAT TESTED			39	76	013	026	25	1 20	65	.08	6 8

BRIN.	555	514	477	461	388	352	311	285	262	223
SHORE	75	70	65	63	54	49	44	40	37	32
ROCK.	C65	C52	C49	C47	C41	C37	C33	C30	C26	C20
IZOD.	35	37	22	24	40	51	66	80	97	105



NORMALIZED AT 1000°F., REHEATED TO 1525°F., QUENCHED IN AGITATED OIL

LABORATORY ACTIVITY AND SKILLS

The student should heat treat specimens and compare hardnesses, for example use the following heat treatments:

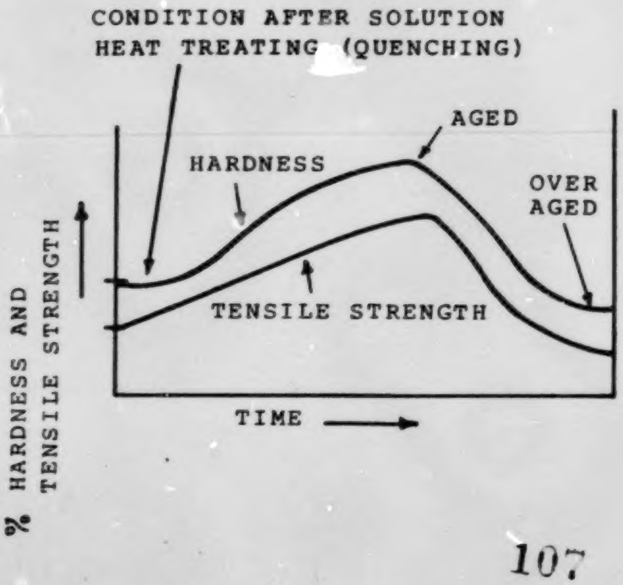
No.	Steel Alloy
3 -	1020 Jominy, Anneal, Normalize, Water Quench
4 -	1050 Jominy, Anneal, Normalize, Water Quench, Oil Quench
5 -	3140 Jominy, Anneal, Normalize, Water Quench, Oil Quench,

then temper, 1050 and 3140 steels at 800°F for two hours.

Section 6 - Heat Treating of Non-ferrous Metals

Non-ferrous metals are hardened by strain hardening, and alloying as we have discussed. Another method is by heat treating of certain alloy mixtures.

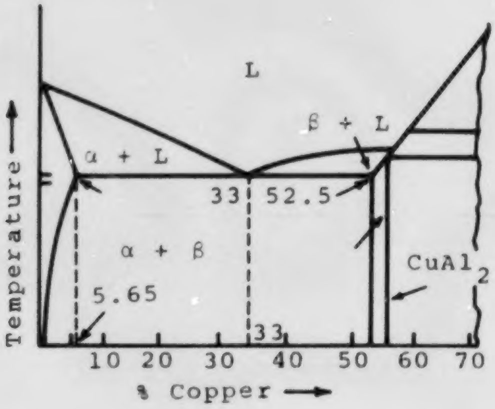
Many non-ferrous alloy compositions which are of a single phase at elevated temperature form a two phase, solid solution as the alloy slowly cools. These alloys may be heat treated by quickly cooling the high temperature single-phase alloy and freezing the solute alloy into the other solid phase. Reheating the super saturated solid solution causes one alloying element to precipitate locking the slip planes in the crystal structure of the solvent metal. The hardness of the alloy depends on the amount of precipitated alloying element. Over-heating of the alloying element will cause reduction in hardness and tensile strength because the alloying element precipitates out of the solid solution allowing the planes of atoms to move more freely.

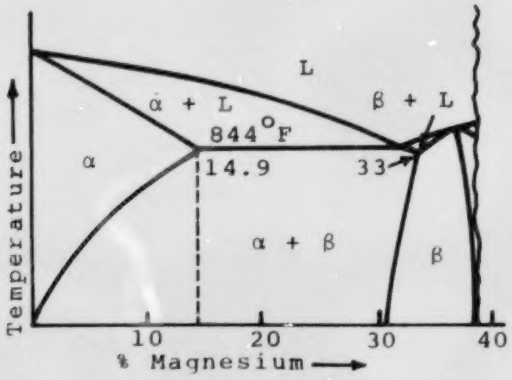


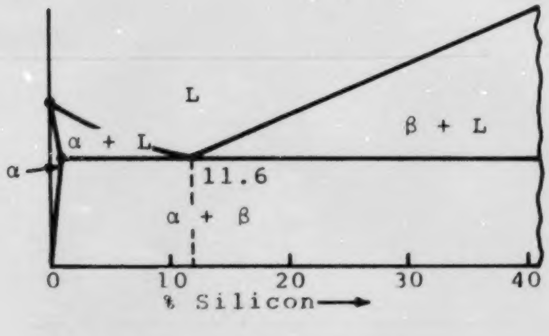
Precipitation at room temperature is natural aging.

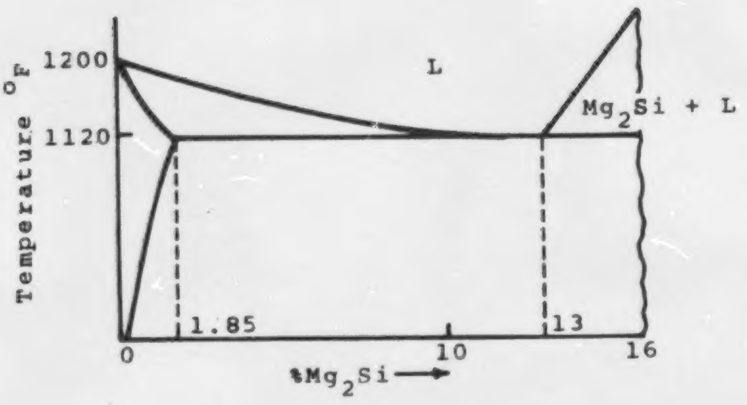
Precipitation at elevated temperature is artificial aging.

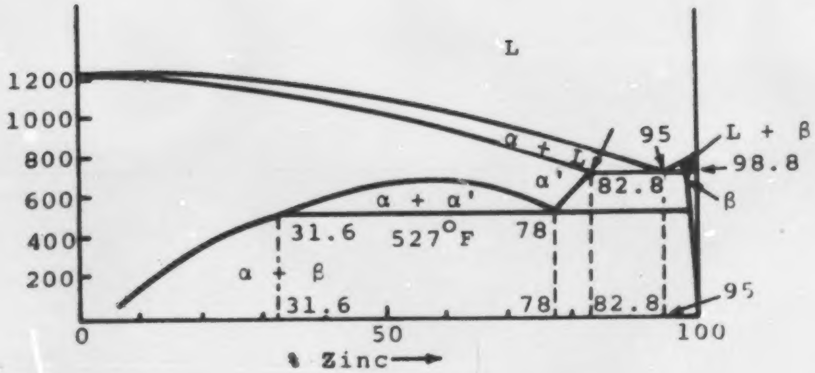
COMMON ALUMINUM ALLOYS WHICH ARE HEAT TREATABLE INCLUDE:


L
β + L
α + L
33
52.5
α + β
CuAl$_2$
5.65
33
Temperature
10 20 30 40 50 60 70
% Copper


L
α + L
β + L
844°F
α
14.9
33
α + β
β
Temperature
10 20 30 40
% Magnesium


L
β + L
α + L
α
11.6
α + β
0 10 20 30 40
% Silicon


Temperature °F
1200
1120
L
Mg2Si + L
1.85
13
0
10
16
%Mg2Si →


L
1200
1000
800
600
400
200
α + L
95
L + β
98.8
α'
82.8
β
α + α'
31.6
527°F
78
α + β
31.6
78
82.8
95
0
50
100
% Zinc →

The Aluminum Alloys Are Designated By Either Wrought Or Cast Alloys.

ALUMINUM

WROUGHT ALLOYS

1 XXX - T6
LS

ALLOY

HEAT TREATING
OPERATION

CONTROL
OF IMPURITIES
1 - 9

ADDITIONAL DIGITS ADDED
FOR MODIFICATIONS
TO OPERATION.

MINIMUM % OF
ALLUMINUM IN
HUNDREDTHS
FOR SERIES
STARTING WITH
1.XXX

TEMPER
0 - ANNEALED
F - AS FABRICATED
H - STRAIN HARDENED
W - UNSTABLE FOLLOWING SOLUTION HEAT TREAT
T - HEAT TREATED

NO SPECIAL
PURPOSE WHEN
SERIES GOES
FROM
2 XXX
9 XXX

CAST ALLOYS

1 XX.X

MAJOR
ALLOY

0 - CASTING
1 - INGOT
2 - VARIATION
FROM ZERO

ASSIGNED NUMBER
FOR A SPCIFIC
ALLOY COMPOSITION..

Material	Designation
Aluminum, 99.00% minimum	1XXX
Major alloys	
Copper	2XXX*
Manganese	3XXX
Silicon	4XXX
Magnesium	5XXX
Magnesium and silicon	6XXX
Zinc	7XXX
Other	8XXX
Unused series	9XXX

---

*Aluminum Standards and Data, 2nd ed., (Dec. 1969), p. 6, Aluminium Association of America.

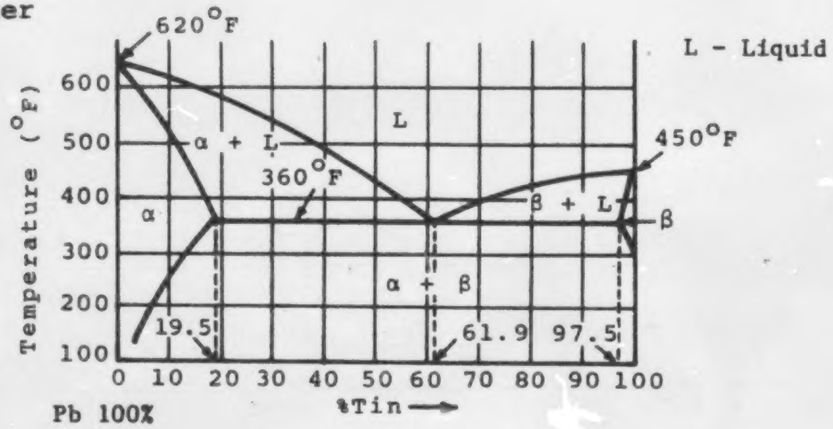
Typical heat treating processes for aluminums are:

Alloy	*Annealing*			*Solutionizing*		*Precipitation Heat-treat*		
	Temp °F	*Time hr*	*Temper*	*Temp °F*	*Temper*	*Temp °F*	*Time hr*	*Temper*
1100	650		–0					
2011	775	2–3	–0	950	–T4	320	12–16	–T6
2014	775	2–3	–0	940	–T4	340	8–12	–T6
2017	775	2–3	–0	940	–T4	—	—	—
2024	775	2–3	–0	920	–T4	375	11–13	–T81
2218	775	2–3	–0	950	–T4	460	5–8	–T72
3003	775		–0					
4032	775	2–3	–0	950	–T4	340	8–12	–T6
5005	650		–0					
5050	650		–0					
5154	650		–0					
6061	775	2–3	–0	970	–T4	320 350	16–20 6–10	–T6
6063	775	2–3	–0			450 365 350	1–2 4–6 6–8	–T5 –T6
6151	775	2–3	–0	960	–T4	340	8–12	–T6
7075	775	2–3	–0	870	–W	250	24–28	–T6

Heavy Metal Alloys

Lead and Tin

Solder



LABORATORY ACTIVITY AND SKILLS

Aluminum alloy such as 2024 or 6061 should be solution heat treated and its hardness measured and/or tensile strength. Crystal structures should be examined if time permits. Both natural aged and artificially aged specimens should be studied.

CHAPTER VI

FINISHES

Section 1 - Types and Indentification

Chemical Conversion Coatings - Surface chemical reaction forms corrosion resistant compound or oxide which is non-porous and durable.

Phosphate

Chromate

Anodic (metal ion)

Oxide & other

Chromic - Phosphate

PLATING - ELECTRO DEPOSITED COATINGS - Metal film is deposited using an electrical cell, thus speeding the deposition rate.

DIFFUSION COATINGS - A heated coating diffuses into material.

FLAME SPRAY COATINGS - A high temperature flame fuses material to the surface of the part to be protected. Metallic and ceramic materials may be sprayed.

HOT DIP - Zinc, aluminum, tin and lead are bonded when the prepared metal surface is dipped in molten coating material.

CHEMICAL IMMERSION - This is a diffusion bond of metal to another metal when powder coating is applied, providing a very thin coat.

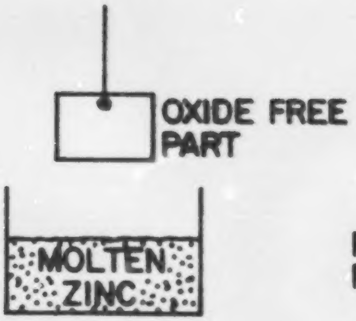
VAPOR - VACUUM DEPOSITED - Atoms of an element are heated in a vacuum for a thin-plated coating on work.

ORGANIC COATINGS - These include paints, lacquers, enamels, that have pigment fillers with hydrocarbon solvents & rosins which coat surfaces. The solvents evaporate forming durable, non-porous coating.

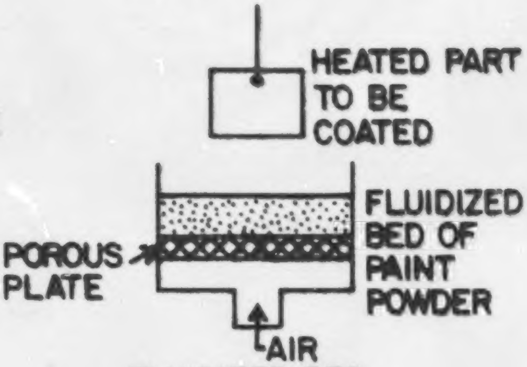
CERAMIC COATINGS - These are porcelain enamels - metal oxide coating in powdered form which with a binder coats parts, and then is heated to form a fused ceramic coating.

Section 2 - Application

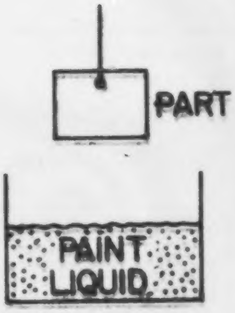
Dipping


OXIDE FREE PART
MOLTEN ZINC

HOT DIP

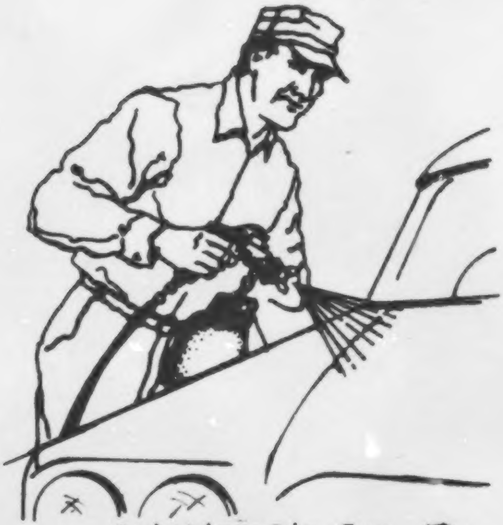

HEATED PART TO BE COATED
FLUIDIZED BED OF PAINT POWDER
POROUS PLATE
AIR

FLUIDIZED BED POWDER COATING

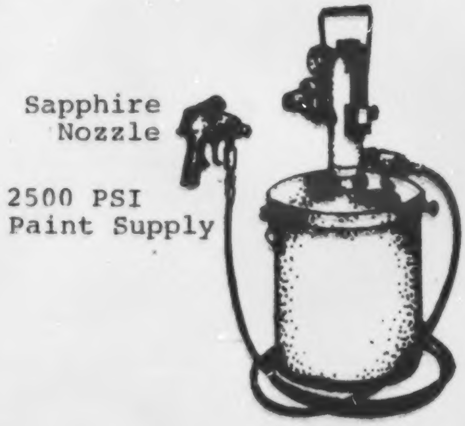

PART
PAINT LIQUID

LIQUID COATING

Spraying

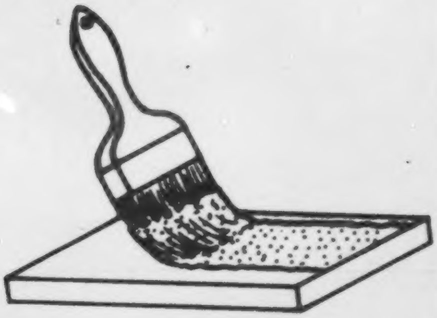


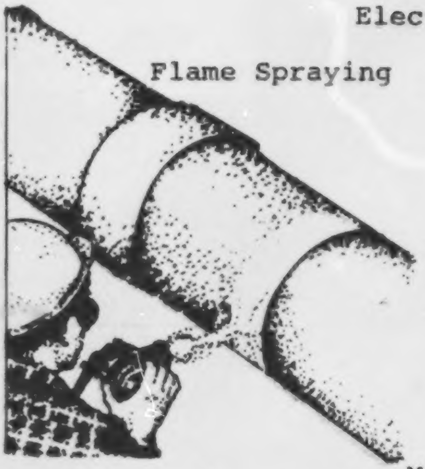
Painting Air Gun


Sapphire Nozzle
2500 PSI Paint Supply

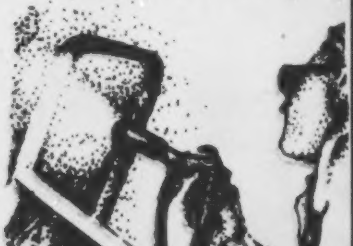
Airless

Electro Static Spraying

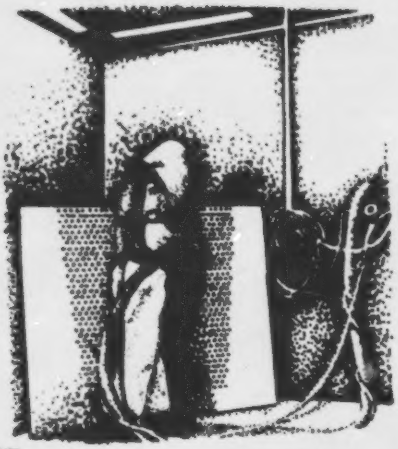




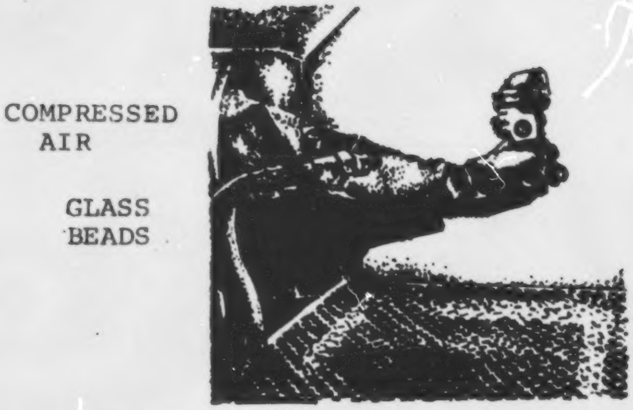
Flame Spraying



Manual Electrostatic Paint Spraying

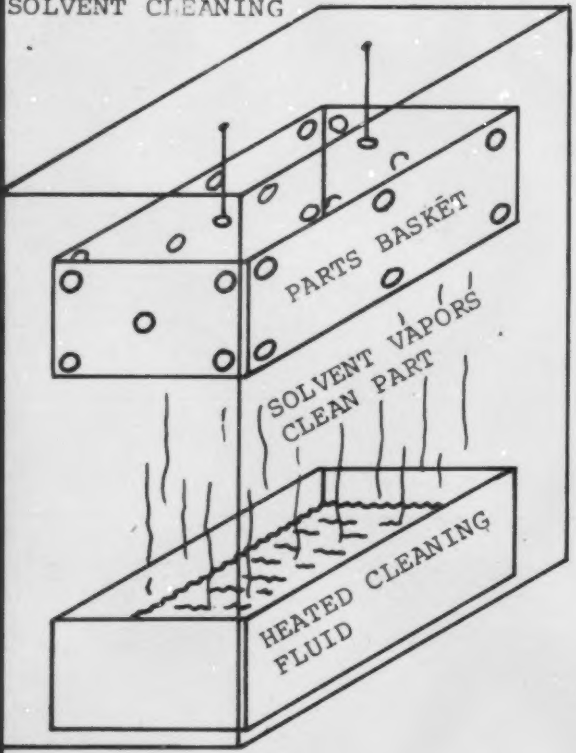


SAND BLAST

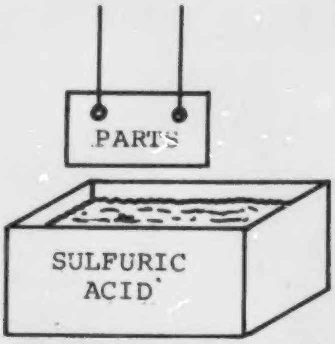

COMPRESSED AIR
GLASS BEADS

GLASS PEEN
Beads striking part
remove brittle oxides.

SOLVENT CLEANING

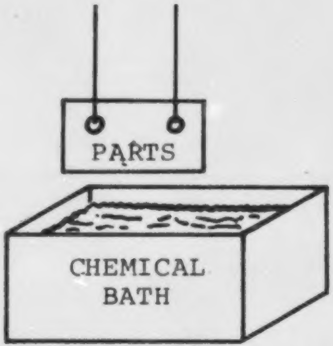

PARTS BASKET
SOLVENT VAPORS CLEAN PART
HEATED CLEANING FLUID

PICKELING


PARTS
SULFURIC ACID

An acid bath removes oxide

ANODIZE


PARTS
CHEMICAL BATH

A chemical bath produces
controlled thickness of
aluminum or magnesium oxide
to resist corrosion and form
base for finish to be applied

Section 4 - Paints, Lacquers, Varnishes and Primers

ENAMELS - Resin-solvent carrier with a pigment filler.

LACQUERS - Fast drying resin-solvent coating.

VARNISH - Resin-solvent coating without pigment.

PRIMERS - Coating which improves bond between part surface and paint coating.

SURFACE COATINGS

Type ➡	Alkyd						Acrylic	Bitum-inous
	Alkyd	Alkyd-Amine	Alkyd-Phenolic	Alkyd-Silicone	Alkyd-Urea	Styrenated Alkyd		
APPLICATION								
Ease of Application	E	Bake req	E	E	Bake req	E	VG	P-VG
Metal Surface Prep	Primer	No primer	No primer	Primer	No primer	No primer	Primer	No primer
Solvent for Appl[d]	Hyd	Hyd	Hyd	Hyd	Hyd	Hyd	Blend	–
Method[b]	U	U	U	U	U	U	U	U
Cure[c]	A or B	B	A or B	A or B	B	A or B	A	A
Bake Drying Time	30 min (275 F)	20 min (320 F)	30 min (350 F)	30 min (350 F)	20 min (320 F)	15 min (300 F)	–	–
Air Drying Times								
Touch	2 hr	–	20 min	45 min	–	10 min	5 min	2 hr
Handle	4 hr	–	60 min	2 hr	–	30 min	15 min	24 hr
Re-Coat	4 hr	–	6 hr	4-6 hr	–	4 hr	15 min	–
Hard	12 hr	–	6 hr	12 hr	–	4 hr	12 hr	24 hr
Corr Res	48 hr	–	48 hr	12 hr	–	48 hr	24 hr	–
Coverage, sq ft/gal/mil	450	450	450	500	450	400	350	–
Coat Thk (avg), mil	1.5	1.5	1.5	0.6	1.5	1.5	1.0	3-250
PHYSICAL PROPERTIES								
Sward Rocker Hard (8th day)	24	30	34	16-30	28	28	24	–
Flexibility	E	VG	G	VG	VG	G	E	E
Abrasion Res, cycles[a]	3500	>5000	>5000	4000	>5000	>5000	2500	–
Max Svc Temp, F	200	250	250	450	225	200	180	200
Toxicity	None	Slight	None	None	Slight	Slight	None	–
Impact Res	VG	E	G	G	E	G	E	E
Dielec Properties	G	G	VG	E	G	G	VG	–
Adhesion to—								
Ferrous Metals	E	E	E.	VG	E	F	VG	E
Nonferrous Metals	F	E	E	VG	VG	F	VG	E
Old Paints	VG	G	G	E	G	VG	P.	–
CHEMICAL RESISTANCE								
Exterior Durability	E	E	E	E	E	G	E	F
Salt Spray	E	VG	E	E	G	G	E	E
Solvents—Alcohols	F	G	G	G	G	G	P	P
Solvents—Gasoline	G	E	E	E	E	F	G	P
Solvents—Hydrocarbons	G	E	E	G	E	F	F	P
Solvents—Esters, Ketones	P	P	F	P	F	P	P	P
Solvents—Chlorinated	P	P	P	P	P	P	P	P
Beverages, Food	F	G	VG	G	G	VG	VG	E
Salts	VG	E	E	VG	E	E	VG	G
Ammonia	P	P	P	P	P	P	P	–
Alkalis	P, P	VG, G	F, P	G,F	G, G	G, VG	G, F	E
Acids—Mineral	F, P, P	G, F, P	VG, G, F	G, P, P	F, P, P	G, F, P	G, F, P	G, –, –
Acids—Oxidizing	P, P, P	F, P, P	G, F, P	P, P, P	F, P, P	F, P, P	F, P, P	–
Acids—Organic (acetic,formic,etc.)	P, P, P	P, P, P	F, P, P	P, P, P	P, P, P	P, P, P	P, P, P	E, –, –
Acids—Organic (oleic, stearic, etc.)	F	G	VG	G	F	F	F	P
Acid—Phosphoric	P	P	P	P	P	P	P	E
Water (salt, fresh)	F	G	G	G	F	G	E	E

RATINGS KEY: E, excellent; VG, very good; G, good; F, fair; P, poor. Two ratings are for 20% and concentrated solutions, respectively. Three ratings are for 10%, 10-30% and concentrated solutions, respectively.

[a] Taber GS-10 wheel. [b] Key: L, limited (i.e., pure white cannot be formulated); SL, slightly limited (difficulty in formulating whites and pastels); U, unlimited (any color can be formulated). [c] Based on white coatings with titanium dioxide pigment. [d] Key: Hyd, hydrocarbons; Alc, alchohols. Key: A, air dried; B, can be baked.

SURFACE COATINGS

Type →	Cellulose			Epoxy					
	Nitro-cellulose	Butyrate	Ethyl Cellulose	Epoxy-Amine	Epoxy-Ester	Epoxy-Furane	Epoxy-Melamine	Epoxy-Phenolic	Epoxy-Urea
APPLICATION									
Ease of Application	VG	VG	VG	Catalyst req	E	E	Bake req	Bake req	Bake req
Metal Surface Prep	Primer	Primer	Primer	No primer	Primer	None	No primer	No primer	No primer
Solvent for Appl[d]	Blend	Blend	Blend	Blend	Hyd	Ketone	Blend	Blend	Blend
Method[b]	U	U	U	U	U	U	L	L	L
Cure[e]	A	A	A	A	A or B	B	B	B	B
Bake Drying Time	–	–	–	–	30 min (320 F)	30 min (350 F)	30 min (350 F)	30 min (400 F)	30 min (350 F)
Air Drying Times									
Touch	5 min	5 min	5 min	60 min	1 hr	–	–	–	–
Handle	15 min	15 min	15 min	2 hr	2 hr	–	–	–	–
Re-Coat	15 min	15 min	15 min	6-8 hr	8 hr	–	–	–	–
Hard	12 hr	12 hr	12 hr	12 hr	8 hr	–	–	–	–
Corr Res	24 hr	24 hr	–	7-10 days	5 days	–	–	–	–
Coverage, sq ft/gal/mil	300	200	300	500	450	450	500	450	500
Coat Thk (avg), mil	1.0	1.0	1.0	1.8	1.5	0.5-1.0	1.8	1.8	1.8
PHYSICAL PROPERTIES									
Sward Rocker Hard. (8th day)	30-50	26	25-30	36	30	24	36	44	34
Flexibility	E	E	E	F	E	E	VG	VG, E	VG
Abrasion Res, cycles[a]	2500	2500	–	>5000	>5000	–	>5000	>5000	>5000
Max Svc Temp, F	180	180	300	400	300	350	400	400	400
Toxicity	None	None	None	None	None	None	None	None	None
Impact Res	E	E	E	G	E	G	VG	VG	G
Dielec Properties	F	G	E	VG	VG	G	VG	VG	VG
Adhesion to—									
Ferrous Metals	VG	VG	P	E	E	E	E	E	E
Nonferrous Metals	G	G	G	E	E	E	E	E	E
Old Paints	P	P	P	G	VG	E	P	P	P
CHEMICAL RESISTANCE									
Exterior Durability	E	E	E	G	E	E	E	E	VG
Salt Spray	E	E	E	VG	E	E	E	E	E
Solvents—Alcohols	G	G	P	G	F	E	E	E	E
Solvents—Gasoline	G	G	P	E	E	E	E	E	E
Solvents—Hydrocarbons	F	F	F	E	VG	E	E	E	E
Solvents—Esters, Ketones	P	P	P	VG.	F	G	VG	E	VG
Solvents—Chlorinated	P	P	P	G	F	E	E	E	E
Beverages, Food	G	G	E	E	VG	E	E	E	E
Salts	G	VG	G	E	E	E	E	E	E
Ammonia	P	P	G	G	P	E	P	F	P
Alkalis	P, P	P, P	G, G	E, E	E, E	E	E, E	E, E	E, E
Acids—Mineral	E, G, F	G, F, P	G, F, P	E, VG, G	G, F, P	G	E, VG, G	E, E, E	E, VG, F
Acids—Oxidizing	P, P, P	P, P, P	F, P, P	G, P, P	F, P, P	F	G, P, P	E, VG, P	F, P, P
Acids—Organic (acetic, formic, etc.)	P, P, P	P, P, P	G, –, –	F, F, P	F, P, P	F, G	G, F, P	E, E, VG	F, P, P
Acids—Organic (oleic, stearic, etc.)	F	F	–	G	E	E	E	E	E
Acid—Phosphoric	E	P	–	G	P	E	G	E	G
Water (salt, fresh)	G	E	E	G	VG	E	G	E	G

RATINGS KEY: E, excellent; VG, very good; G, good; F, fair; P, poor. Two ratings are for 20% and concentrated solutions, respectively. Three ratings are for 10%, 10-30% and concentrated solutions, respectively.

[a] Taber GS-10 wheel. [b] Key: L, limited (i.e., pure white cannot be formulated); SL, slightly limited (difficulty in formulating whites and pastels); U, unlimited (any color can be formulated). [c] Based on white coatings with titanium dioxide pigment. [d] Key: Hyd, hydrocarbons; Alc, alchohols. Key: A, air dried, B, can be baked.

Section 5 - Identification and Uses of Plating

Plate ♣	Basic Materials	Hardness	Abrasion Resistance	Important Characteristics and Uses
Aluminum	Steel, iron, copper, magnesium, silver, gold, zinc, nickel	30-90 Vickers	Poor	Porous, poor physical properties; good thermal and heat resistance properties when diffused into base metal. Infrequently used; can substitute for hot dipped aluminum
Antimony	–	Intermediate	–	Tarnish resistant, pleasing appearance when polished. However, coatings too brittle for practical application
Arsenic	Brass	–	–	Infrequently used to provide decorative antique effect
Bismuth	–	Comparable to lead	–	Somewhat expensive. Infrequently used for corrosion protection
Cadmium	Steel, stainless steel, wrought iron, gray and malleable iron, copper and its alloys	30-50 DPH	Fair	Pleasing appearance provides good corrosion protection indoors on iron and steel. Less apt to darken and form corrosion products than zinc; nevertheless, zinc is more widely used because of lower cost. Outdoor corrosion resistance varies and should be checked by testing. Radio, television and electronic chassis; aircraft, marine and military outdoor uses
Chromium, including colored	Ferrous, nonferrous metals, ABS, polypropylene, polysulfone, phenolic	900-1100 Vickers	Excellent	Excellent resistance to wear, abrasion and corrosion. Low coefficient of friction and high reflectivity. Popular decorative corrosion resistant coating on automobile exterior and interior trim, appliances and business machines. Widely used in bearing applications and to build up worn surfaces
Cobalt	Iron, steel, copper and its alloys	250-350 Knoop	Good	Similar to nickel, but more expensive. Infrequently used alone except for applications where high hardness is needed and on mirrors and reflectors. Frequently used in alloy electroplates to upgrade properties
Copper	Most ferrous, nonferrous metals, ABS, polypropylene, polysulfone, phenolic	41-220 Vickers	Poor	Good appearance (when polished and/or lacquered) and corrosion resistance; high electrical and thermal conductivity. Undercoat to improve adhesion and protective ability of subsequent electroplates (e.g., nickel and chromium) or to prevent hydrogen embrittlement. Also used as wire coatings stop-off coatings during heat treatment and chemical milling, lubricant during drawing, thermally conductive coatings on cooking utensils, and for electroforming
Gold	Copper, brass, nickel, silver, some plastics	65-125 kn for gold; 150-325 for 1% Ni alloys; 450 for 30% Ni alloys	Poor-Good	Resistant to tarnishing, chemical attack, and high temperature oxidation. Good ductility, thermal reflectivity and electrical conductivity. Pen points, jewelry, watch and vanity cases, musical instruments, reflectors, nameplates, eyeglass frames, bracelets, trophies, novelties, electrical contacts, springs, waveguides, various electronic parts, laboratory apparatus
Indium	Silver-plated steel, lead-bearing metals	Soft	Poor unless diffused	Tarnish resistant, malleable, and ductile. Principally used as an overlay diffusion coating on silver plated steel bearings for high speed aircraft engines. Also used as an alloying element to upgrade mechanical properties of alloy coatings
Iron	Ferrous metals	125-400 Bhn	Very good	Can be deposited with selected properties; easily fabricated and plated over; high purity. Build-up of undersized parts, electrotypes, electroforming of molds
Lead	Ferrous metals, copper	5 Bhn	Poor (but alloy coatings have good bearing properties)	Resistant to many acids, hot corrosive gases, and corrosive atmospheres. Lead normally desposited by hot dipping; however, lead electroplates are used to protect chemical equipment, brine refrigerating tanks, metal gas shells, nuts and bolts, and storage battery parts
Nickel	Most ferrous, nonferrous metals, ABS, polypropylene, polysulfone, phenolic	140-500 DPH	Good-very good	Excellent appearance, and resistant to a wide variety of chemicals and corrosive atmospheres; can be electroplated in range of hardness (soft to hard). Decorative applications either alone or as a heavy base for thin chromium electroplates to improve corrosion resistance and mechanical properties, as in trim for automobiles appliances, business machines and consumer goods. Also used for electroforming, and to build up worn and mismachined parts
Palladium	Copper and its alloys plus underplate of silver, gold or platinum	255-265 Knoop	–	Good appearance, tarnish and corrosion resistance, Ornamental and decorative applications. Can be used alone or under rhodium for radar and electronic equipment

Plate ↓	Basis Metals	Hardness	Abrasion Resistance	Important Characteristics and Uses
Platinum	Gold, copper alloys	280-290 Knoop	Poor	Good appearance, tarnish and corrosion resistance. Ornamental ("white gold") applications and as a flash decorative coating. Also to protect surfaces that must withstand unusual corrosive environments
Rhenium	–	250 Bhn	–	Although melting point is high, begins to oxidize as low as 752 F. Poor resistance to moisture. Infrequently used but has been proposed for electronic applications such as cathode and filament emitters and heater wires
Rhodium	Most ferrous, nonferrous metals, over Ni on ABS, polypropylene, polysulfone	400-800 Bhn	High	Brilliant white color, tarnish and corrosion resistant, good electrical conductivity. Decorative and tarnish resistant finish for costume jewelry, insignia, emblems, musical instruments, medical and surgical parts, laboratory equipment and optical goods. Also electrical contacts, reflectors and mirrors
Silver	Most ferrous, nonferrous metals, over Ni on ABS, polypropylene, polysulfone	50-150 Bhn	Good	Excellent appearance when suitably prepared and protected, high load-carrying capacity and electrical conductivity, good resistance to many chemicals. Decorative applications, such as tableware, hollow-ware, cigarette lighters and musical instruments. Also industrial applications, such as bearings, surgical instruments, chemical equipment, electrical contacts, etc., where conductivity is needed
Tin	Usually ferrous metals	5 Bhn	Poor unalloyed	Corrosion resistant, attractive appearance, hygienic, easily soldered, soft and ductile, good bearing properties. Food and beverage containers, refrigerator evaporators, food and dairy equipment, hardware, appliance and electronic parts, copper wire, and bearings
Zinc	Usually ferrous metals		Poor	Easily and rapidly applied, high corrosion resistance. Electrogalvanized sheet is widely used in fabricating appliance and automotive parts. Also, for finishing small parts such as pipe couplings, bolts, nuts, rivets, washers, nails, hinges, hangers, hooks and buckles. Larger parts include electrical conduit pipe, silo and tie rods, screening, telephone exchange equipment, and iron and sheet castings
Cobalt-Nickel	–	350-450 DPH	Very good	Wide range of magnetic properties. Magnetic recording, permanent magnet coating on memory drums in digital computers. Electroforming
Copper-Tin (Bronze)	Steel, copper, brass, zinc, over Ni on some plastics	150-250 DPH	Good	Red bronze coatings (lacquered to prevent tarnishing) used on inexpensive jewelry, door plates, hardware, trophies, handbag frames; as undercoat for nickel and chromium; as stop-off coating in selective nitriding of steel; also used on bearing surfaces. Speculum coatings (40-50% tin) used for tableware and household fixtures; not recommended for outdoor use
Copper-Zinc (Brass)	Iron, steel, aluminum, zinc, over Ni on some plastics	Soft	Poor	Rich appearance much like solid brass. Little resistance to outdoor atmospheres; may require lacquer coating to resist indoor tarnishing. Decorative applications such as lamps and trays; low cost trim, interior automotive hardware, tubular furniture, household goods, toys, casket hardware, novelties. Also used to promote adhesion of rubber to steel
Lead-Tin	Steel, copper, brass, over Ni on some plastics	Soft	Poor	Harder and more protective than lead; good friction and bearing properties. Heavy duty bearing where corrosion protection is needed, and as an aid in soldering
Tin-Nickel	Most ferrous, nonferrous metals	625 Vickers	Good	Good decorative properties (resembles chromium); high resistance to tarnishing, common reagents, and marine corrosion; good bearing and oil retention properties; solderable. Plating baths have outstanding throwing properties. Cooking utensils, analytical weights and surgical instruments, numerous watch parts, chemical pumps, valves and flow control devices
Tin-Zinc	Most ferrous, nonferrous metals	Similar to tin	Good	Good corrosion resistance, excellent solderability, tendency to fingermark (can be prevented by lacquering). Radio and television parts, cable connectors, relay assemblies, galvanic protection of steel parts contacting aluminum

LABORATORY ACTIVITY AND SKILLS

The student should examine and identify different types of finishes and be guided in observing the many uses for the different coatings.

The student should experiment with dip coating, spraying, brushing and plating of parts being made.

The student should be familiar with methods of surface preparation and should prepare metal part surfaces for finishing. Wood may be included.

The student should learn properties and applications of paints and primers by examining and applying paints to wood, plastic and metal.

The student should learn to identify plating types and their uses. Plating should be done as a laboratory project.

STUDENT PROBLEMS

1. Coatings may be classified by their method of application. List three coating types.
2. Steel may be coated with ______________________________ to prevent corrosion.
3. A good paint coating for repairing equipment with old paint is ________________________________.

APPENDIX

TABLE #1

Properties of Metals

Material	*Density lb/in.³*	*Sp. gr.*	*Hardness BHN*	*Thermal expansion 10⁻⁶ in/in/°F*	*Tensile elastic 10⁶ psi*	*Torsion mod. 10⁶ psi*	*Yield st. 0.2% offset × 10³ psi*	*Tensile st. 10³ psi*	*Elongation in 2 in. %*
Carbon st (1020)									
Annealed	0.284	7.86	130	6.7	30	16	38	65	30
Hot rolled			135				42	68	32
Hardened			179				62	90	25
Gray cast iron	0.260	7.20	180	6.7	13		6	25	0.5
Malleable iron	0.264	7.32	130	6.6	25		33	52	12
Steel (stainless)									
302 annealed	0.281	7.80	155	10.0	28		35	90	60
304 annealed	0.281	7.78	150	10.0	28		30	80	45
431 annealed	0.280	7.75	250	6.5	29	10.6	85	120	25
Wrought iron	0.278	7.70	100	6.35	29		30	48	30
Aluminum									
Annealed	0.103		23		10.4		5	13	45
Cold rolled	0.098	2.71	32	13	10	3.8	17	18	20
Copper									
Annealed			42				10	32	45
Cold drawn	0.322	8.9	90	9.3	17	6.4	40	45	15
Magnesium									
Sand cast	0.066	1.83	50	14.5	6.5	2.4	14	24	6
Manganese-Bronze									
Cold drawn	0.302	8.36	180	11.2	15	5.6	50	80	20
Nickel									
Annealed	0.322	8.91		7.8	30	11	8.5	46	30
Red brass									
Cold drawn	0.316	8.75	120	9.8	17	64	55	70	15
Titanium									
Annealed	0.163	4.54	200	5.0	16.5	6.6	70	90	23

Properties and major characteristics of common types of plastics

Material	Specific Gravity	Tensile-Strength 1,000 lb. per sq. in.	Impact Strength Izod ft.-lb./in. of Notch	Top Working Temper-ature °F.	Dielectric Strength Volts/mil.[a]	24-hour Water Absorp-tion %	Special Characteristics[b]				Common Forms									
							Weatherability	Colorability	Optical Clarity	Chemical Resistance	Injection Molding	Extrusions	Formable Sheet	Film	Fiber	Compression or Transfer Moldings	Castings	Reinforced Plastics Moldings	Industrial Thermo-setting Laminates	Foam
Thermoplastics																				
ABS Material	1.02–1.06	4–8	1.3–10.0		300–400	0.2–0.3	0	✓		0	✓	✓	✓							
Acetal	1.4	10	1.5	250	1200	0.22		✓		0	✓	✓								
Acrylics	1.12–1.19	5.5–10	0.2–2.3	200	400–530	0.2–0.4	✓		✓	0	✓	✓	✓		✓		✓			
Cellulose Acetate	1.25–1.50	3–8	0.75–4.0	145–260	300–600	2.0–6.0		✓	✓		✓	✓	✓	✓	✓					
Cellulose Acetate Butyrate	1.18–1.24	2–6	0.6–3.2	130	250–350	1.8–2.1	✓	✓	✓		✓	✓	✓	✓						
Cellulose Propionate	1.19–1.24	1–5	0.8–9	140	300	1.8–2.1		✓	✓		✓	✓	✓	✓						
Chlorinated Polyether	1.4	6	3.3	300	400	0.01				✓	✓	✓								
Ethyl Cellulose	1.16	3–6	1.8–4.0	150	350	1.6–2.2		✓			✓	✓								
TFE-Fluorocarbon	2.1–2.3	1.5–3	2.5–4.0	500	450	0	✓			✓		✓	✓	✓	✓	✓				
CFE-Fluorocarbon	2.1–2.15	4.5–6	3.5–3.6	390	550	0	✓			✓	✓	✓	✓	✓						
Nylon	1.1–1.2	8–10	2	250	385–470	0.4–5.5		0	0	0	✓	✓	✓	✓	✓					
Polycarbonate	1.2	9.5	14	250	400	0.15	✓	0		✓	✓	✓								
Polyethylene	0.96	4	10	200	440	0.003		0	✓	✓	✓	✓	✓	✓	✓					✓
Polypropylene	0.9–1.27	3.4–5.3	1.02	230	520–800	0.03		0	✓	✓	✓	✓	✓	✓	✓					
Polystyrene	1.05–1.15	5–9	0.3–0.6	150–190	400–600	<0.2		✓	✓	0	✓	✓	✓	✓						
Modified Polystyrene	1.0–1.1	2.5–6	0.25–11.0	212	300–600	0.03–0.2		✓		✓	✓	✓	✓	✓						
Vinyl	1.16–1.35	1–5.9	0.25–2.0	220	25–500	0.2–1		✓	✓	✓	✓	✓	✓	✓	✓		✓			✓
Thermosetting Plastics																				
Epoxy	1.1–1.7	4–13	0.4–1.5	325	500	0.1–0.5	✓	✓		✓							✓	✓	✓	✓
Melamine	1.76–1.98	5–8		350	460	0.1		✓		0						✓		✓	✓	
Phenolic	1.2–1.45	5–9	0.25–5	300	100–500	0.2–0.6				0						✓	✓	✓	✓	✓
Polyester (other than molding compounds)	1.06–1.46	4–10	0.18–0.4	300	340–570	0.5		✓	✓	0				✓	✓		✓	✓	✓	
Polyester (alkyd, DAP)	1.6–1.75	3.2–8	3.6–8			0.16–0.67										✓		✓	✓	
Silicone	2.0	3–5	0.2–3.0	550	250–350	0.4–0.5										✓	✓	✓	✓	✓
Urea	1.41–1.80	4–8.5	0.2–0.5	160–185	300–600	1–3		✓		0										

[a] Short-time ASTM Test.
[b] ✓ denotes a principal reason for its use 0 indicates a secondary reason

TABLE #1 CONT.

Properties and uses of common elastomers.

Elastomer	Specific Gravity	Durometer Hardness	Tensile Strength, psi Pure Gum	Black	Elongation, % Pure Gum	Black	Service Temp. °F Min.	Max.	Resistance to: * Oil	Water Swell	Tear	Typical Applications
Natural rubber	0.93	20–100	2,500	4,000	750	650	−65	180	P	G	G	Tires, gaskets, hose
Polyacrylate	1.10	40–100	350	2,500	600	400	0	300	G	P	F	Oil hose, O-rings
EDPM (Ethylene propylene)	0.85	30–100	1	3†		500†	−40	300	P	G	G	Electric insulation, footware, hose, belts
Chlorosulfonated polyethylene	1.10	50-90	4	2†		400†	−65	250	G	E	G	Tank linings, chemical hose, shoe soles and heels
Polychloroprene (Neoprene)	1.23	20–90	3,500	4,000	800	550	−50	225	G	G	G	Wire insulation, belts, hose, gaskets, seals, linings
Polybutadiene	1.93	30–100	1,000	3,000	800	550	−80	212	P	P	G	Tires, soles and heels, gaskets, seals
Polyisoprene	0.94	20–100	3,000	4,000		600	−65	180	P	G	G	Same as natural rubber
Polysulfide	1.34	20–80	350	1,000	600	400	−65	180	E	G	G	Seals, gaskets, diaphragms, valve disks
SBR (Styrene Butadiene)	0.94	40–100	2			1,200†	−65	225	P	G	G	Molded mechanical goods, disposal pharmaceutical items
Silicone	1.1	25–90		1,200†		450†	−120	450	F	E	P	Electric insulation, seals, gaskets, O-rings
Epichlorohydrin	1.27	40–90		2†		325†	−50	250	G	G	G	Diaphragms, seals, molded goods, low-temperature parts
Urethane	0.85	62–95	5,000		700		−65	212	E	F	E	Caster wheels, heels, foam padding
Fluoroelastomers	1.65	60-90	1	3†		400†	−40	450	E	E	F	O-rings, seals, gaskets, roll coverings

* P = poor; F = fair; G = good; E = excellent.

† = reinforced.

TABLE # 2

TYPE	MANUFACTURER	NAME	WORKING CHARACTERISTICS				BOND PROPERTIES				BEST USES
		COMMON ADHESIVES NAME	FLAMMABILITY	OPEN TIME (MIN.)	SET TIME	CURE TIME (HRS.)	STRENGTH	FLEXIBILITY	MAX. TEMP. RESISTANCE (°F)	WEATHER RESISTANCE	
CONTACT CEMENTS — SOLVENT SOLUTIONS	Devcon Corp. Danvers, Mass.	Devcon rubber	Yes	10	Instant	48	Medium	Flexible	120	Good	• Nonstructural bonding of wood, paper, fabrics, rubber, leather, glass, cork, felt, foam plastics, foam rubber, linoleum, plastics, carpet. • Laminating veneers and plastic composition panels to wooden Counter tops and flat surfaces. • Bonding plywood wall panels. • Bonding nameplates and fixtures having large flat bond areas to concrete, stucco, plaster, tile, glass, brick, and wood.
	Goodyear Tire & Rubber Co. Akron, Ohio	Pliobond	Yes	5	Instant	48	Medium	Flexible	120	Excellent	
		Sears Miracle Pliobond									
	Sears, Roebuck & Co. Chicago, Ill.	Craftsman contact cement	Yes	30	Instant	24	Medium	Flexible	120	Excellent	
	U. S. Plywood Kalamazoo, Mich.	Weldwood contact cement (tube) (bottle)	Yes	30	Instant	24	Medium	Flexible	120	Excellent	
	Wilhold Glues Inc. Santa Fe Springs, Calif.	Contact cement	Yes	30	Instant	24	Medium	Flexible	120	Excellent	
		Fire-Safe contact cement	No	30	Instant	24	Medium	Flexible	120	Excellent	
		Glu-on fixture adhesive	Yes	5	Instant	24	Medium	Flexible	120	Excellent	
	Woodhill Chemical Corp. Cleveland, Ohio	Duro contact cement	Yes	30	Instant	24	Medium	Flexible	120	Excellent	
		Woolworth's contact cement									
	DAP Inc. Dayton, Ohio	Duratite contact cement	Yes	30	Instant	24	Medium	Flexible	120	Excellent	
	Franklin Glue Co. Columbus, Ohio	Contact cement	Yes	30	Instant	24	Medium	Flexible	120	Excellent	
		Contact cement, water-base	No	60	Instant	96	Medium	Flexible	120	Good	
	Montgomery Ward & Co. Chicago, Ill.	Ward's contact cement	Yes	30	Instant	24	Medium	Flexible	120	Excellent	
		Ward's abrasive-disk cement	No	30	Instant	Instant	Medium	Flexible	200	Good	• Bonding paper disks to sanders.
RUBBER CEMENTS — SOLVENT SOLUTIONS	Global Adhesives Corp. Hempstead, N. Y.	Gripit (1—see footnote)	Yes	30	Instant	24	Low	Flexible	100	Good	• Nonstructural and decorative bonding of paper, foil, fabric, felt, cardboard, cork, plastic film, foam rubber, foam plastic—like to like, or to metal, wood, or glass. • Repairing delaminated wallpaper. • Making double-backed tapes. • Bonding indoor/outdoor carpet and carpet tiles. • Bonding pottery, tile, wood, metal sills, nameplates to concrete. • Nonstructural bonding of paper foil, fabric, felt, cardboard, cork, plastic film, foam rubber, and foam plastics to metal, wood, glass. • Bonding & sealing rubber/cork composition gaskets & rubber hose connections to metal. • Sealing automobile windows, bonding weatherstrip and rubber seals to metal, wood, and glass.
	Ozite Corp. Libertyville, Ill.	Ozite AP680 (1)	Yes	1	Instant	24	Low	Flexible	100	Good	
	3M Company St. Paul, Minn.	Scotch Grip 77 (1)	Yes	5	Instant	24	Low	Flexible	100	Good	
	Miracle Adhesives Corp. Bellmore, N. Y.	Black Magic	Yes	1	30 min.	48	Low	Semirigid	100	Good	
		Brite Magic	Yes	1	30 min.	48	Low	Semirigid	100	Good	
	Permatex Co., Inc. Brooklyn, N. Y.	High-Tack super adhesive No. 975	Yes	½	3 hrs.	48	Low	Flexible	120	Excellent	
	Poly-Chemical Corp. Chicago, Ill.	Strip-Cure	Yes	5	2 hrs.	48	Low	Flexible	100	Good	
	Woodhill Chemical Corp. Cleveland, Ohio	Duro gasket cement No. 2	Yes	1	60 min.	48	Low	Flexible	120	Good	
		Duro black rubber sealant	Yes	5	60 min.	48	Low	Flexible	120	Good	
	DAP Inc. Dayton, Ohio	Duratite contact cement	Yes	5	2 hrs.	48	Low	Flexible	120	Good	
	W. J. Ruscoe Co. Akron, Ohio	Reliebond	Yes	1	8 hrs.	48	Medium	Flexible	150	Excellent	
		Tarp-N-Tent cement	Yes	15	4 hrs.	48	Low	Flexible	120	Good	• Canvas-tent and tarp repair (5).
	Montgomery Ward & Co. Chicago, Ill.	Ward's rubber repair kit	Yes	15	30 min.	48	Medium	Flexible	150	Good	• Rubber-goods, tire, boat repair
MASTIC ADHESIVE	Essex Chemical Corp. Peabody, Mass.	Webtex 200 acoustical adhesive	Yes	½	Instant	48	Low	Semirigid	120	Good	• Bonding acoustical or insulating tile to plaster or concrete. • Installing plywood paneling, gypsum wallboard, prefinished hardboard. • Bonding plastic foam panels (styrene). • Repairing loose brick, slate, tile (6). • Installing plywood panels (7). • Installing vinyl, rubber, tile (8). • Installing plywood paneling, gypsum wallboard, hardboard.
	DAP Inc. Dayton, Ohio	Panel and drywall adhesive (2)	Yes	10	1 hr.	48	Medium	Flexible	180	Excellent	
	Franklin Glue Co. Columbus, Ohio	Panel adhesive (2)	Yes	45	10 min.	48	Medium	Flexible	120	Good	
		Panel and foam adhesive (2)	No	45	1 hr.	48	Medium	Flexible	120	Good	
		Construction adhesive (2)	Yes	45	10 min.	48	Medium	Flexible	180	Excellent	
		Tileboard adhesive	Yes	30	30 min.	48	Medium	Flexible	120	Good	
		Multipurpose floor-tile adhesive	No	30	1 hr.	48	Medium	Flexible	120	Good	
	W. J. Ruscoe Co. Akron, Ohio	Pan-L-Bond	Yes	10	1 hr.	48	Medium	Flexible	180	Excellent	
HIDE OR ANIMAL GLUE	Le Page's Pittsburgh, Pa.	Le Page's Original Glue	No	30	12 hrs.	48	High	Rigid	100	Poor	• Structural bonding and laminating of wood: indoor furniture, cabinets, and veneers.
	Sears, Roebuck & Co. Chicago, Ill.	Craftsman hide glue	No	30	12 hrs.	48	High	Rigid	100	Poor	
	Franklin Glue Co. Columbus, Ohio	Liquid hide glue	No	30	12 hrs.	48	High	Rigid	100	Poor	
	Montgomery Ward & Co. Chicago, Ill.	Liquid hide glue	No	30	12 hrs.	48	High	Rigid	100	Poor	
HOT-MELTS & GLUE GUN	Sears, Roebuck & Co. Chicago, Ill.	Glue Gun (4)	No	—	½ min.	—	Medium	Semirigid	100	Fair	• Bonding wood, leather, fabric, thin metals, and plastics.

TABLE #3

SELECTING PLASTIC ADHESIVES

	Acetal	Acrylics	Cellulose acetate	Cellulose acetate butyrate	Cellulose nitrate	Ceramics	Glass	Metal	Nylon	Phenolic	Poly-carbonate	Styrene	Urea	Vinyl, flexible	Vinyl, rigid	Wood
Acetal	E,R	B,E, R	R,E	R,E	R,E	E,R	E,R	E,R	E,R	E,R	E,R	E,R	B,E, R	S,B, R	B	E,R
Acrylics	B,E	M,S, B	B,E	B,E	B,E,	B,E, R	R,E, B	E,R, B	R,E, B	E,R, B	B,R, S	S,R, B	E,R,			B,R, E
Cellulose acetate	R,E	E,B	S,B	B	B,S	B	R	R,E	R,E	R,E	B,R	R	E,R	R	E	B
Cellulose acetate butyrate	R,E	B	B	B	B	E,R	E,R	E,R	R,E	E,R	B,R	E,R	E,R	R	E,R	B
Cellulose nitrate	R,E	R,E, S	S,B	S,B	S	B,R	B,R	R,E	R,E	R,E	R,E	E,B, R	E,R	R	R,E	B
Nylon	E,R	R,E	R	R	R	E,R, S	R,E	R,E	S,B	S	R,E	R	R,E	R	R	R,E
Phenolic	E,R	E,R	R,E	R,E	R,E	E,R	E,R	E,R	S,E	S,E	E	R,E	R	R,E	R,E	E,R
Polycarbonate	E,R	M,R, E	E,R	E,R	E,R	E,R	E,R	E,R	E,R	E,R	S,E, R	E,B	E,R	R,E	E,R	E,R, B
Polyester	E,R	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Styrene	E,R	R,B	R	R	R	R,B	R,B	B,R	R,B	R,B	R,B	R	R,B	R,B	R,B	R,B
Vinyl, flexible	B	S,B, R	B	B,R	B,R	B,R	B,R	R,B, E	R,E	R,E	B	R,E	E,R	S,R, B	S	B,R
Vinyl, rigid	B	B,R	R,B	B	B,R	B,R	R,B	R,E, B	B,R	E,R	R,B	B,R	E,R	B,R, S	S,B	R,B

Abbreviations and definitions:

M — Monomeric cements, based on a specific plastic which must be catalyzed to produce a strong bond.

S — Solvent cements, which dissolve the plastic to provide molecular interlocking, then evaporate. Normally they require close fitting joints, produce strong bonds.

B — Bodied adhesives contain a thermoplastic or thermosetting resin, and solvents, sometimes plasticizers, which dry by evaporation. The bodied adhesives can compensate for substantial variations in mating surfaces while still providing strong joints.

R — Elastomeric adhesives, based on natural or synthetic rubbers. Some contain the rubber in solvent or water suspension or solution. They may be cured at room or elevated temperatures to provide extremely strong joints.

E — 100% reactive adhesives which depend upon catalytic action to join the two materials with an interlayer of thermosetting resin. The various dry and liquid epoxies, the polyesters, and the phenolics are being considered in this category.

Polyethylene can be bonded only by some of the rubber based cements with extremely low joint strengths.
Fluorocarbons can be bonded to themselves and to other materials only if pretreated or etched. Normally, epoxy adhesives are used. Joint strength is moderate.

TABLE #4

PLASTICS BURNING IDENTIFICATION CHART

PLASTIC	EASE OF LIGHTING	SELF EXTINGUISHING	ODOR	NATURE OF FLAME	BEHAVIOR OF MATERIAL
Acetal	Moderate	No	Formaldehyde	Clean blue flame, no smoke	Melts, drips, drippings may burn
Acrylic	Readily	No	Fruit–like	Blue flame; yellow top, spurts	Softens, usually no drip, little char left
Acrylonitrile Butadiene Styrene	Readily	No	Characteristic[1]	Yellow flame; black smoke.	Softens, drips, chars
Cellulose Acetate	Readily	No	Acetic acid, burned sugar	Dark yellow flame; some sooty black smoke	Melts, drips, drippings continue to burn
Cellulose Acetate Butyrate	Moderate	No	Rancid butter	Dark yellow flame with blue edges, some black smoke	Melts, drips, drippings continue to burn
Cellulose Nitrate	Very readily	No, burns fast	Sharp	White flame; very rapid	Material burns completely
Cellulose Propionate	Readily	No	Fragrant	Blue flame; yellow top, sparks, some black smoke	Melts, drips, drippings continue to burn
Diallyl Phthalate	Difficult	Yes	Characteristic[1]	Yellow; black smoke	Softens, chars
Epoxy	Readily	No	Characteristic[1]	Yellow; spurts black smoke	Chars
Ethyl Cellulose	Readily	No	Burned sugar	Yellow flame; blue top and edges	Melts, drips, drippings continue to burn
Ionomer	Readily	No	Burning paraffin	Yellow–orange flame; blue edges, slight black smoke	Melts, bubbles, drips and burns, chars
Melamine Formaldehyde	Difficult	Yes	Ammonia and formaldehyde	Light yellow	Swells, cracks, turns white at edges
Nylon	Moderate	Yes	Burned wool	Blue flame; yellow top	Melts, drips, froths
Phenolic, molded	Very difficult	Yes	Burned fabric, phenolic	Yellow; a little black smoke, sparks	Cracks badly, chars, swells
Polyallomer	Readily	No	Stringent paraffin	Yellow flame; blue bottom edge, black smoke	Melts clear, spurts, drippings burn
Polycarbonate	Difficult	Yes	Sweet carbon odor	Yellow flame; dense black smoke, carbon in the air	Softens, spurts, chars, decomposes
Polyester	Moderate	No	Burning coal	Yellow; black smoke, burns steadily	Softens, no drips, continues to burn
Polyethylene	Readily	No	Burning paraffin	Blue flame; yellow top	Melts, drips, drippings may burn, swell
Polyphenylene Oxide	Moderate	No	Sweet paraffin	Yellow–orange flame; dense black smoke, carbon in the air	Softens, spurts, chars, decomposes
Polypropylene	Readily	No	Burning paraffin	Blue flame; yellow top, some white smoke	Melts, swells, drips
Polystyrene	Readily	No	Illuminating gas	Orange–yellow flame; dense smoke, clumps of carbon in air	Softens, bubbles
Polysulfone	Readily	No	Pungent sulfur odor	Yellow–orange flame; black smoke, sparkles, carbon in air	Softens, chars, decomposes
Polyurethane	Readily	No	Faint apple odor	Light yellow spurting flame; slight black smoke	Melts, drips, drippings burn
Polyvinyl Acetate	Readily	No	Acetic acid	Dark yellow flame; spurts, black smoke, carbon in the air	Softens
Polyvinyl Chloride	Difficult	Yes	Hydrochloric acid, chlorine	Yellow flame; green on edges, spurts green and yellow, white smoke	Softens
Polyvinylidene Chloride	Very difficult	Yes	Chlorine	Yellow flame; green on edges, spurts green smoke	Softens, chars, leaves ash
Styrene Acrylonitrile	Readily	No	Illuminating gas and acrylonitrile	Yellow flame; heavy black smoke, some carbon in air	Melts, bubbles, chars more than styrene
Tetrafluoroethylene	Will not ignite	Yes	Very little odor	Yellow; green near base	Melts, bubbles, slight charring
Urea Formaldehyde	Difficult	Yes	Strong pancake odor	Pale yellow flame; light greenish–blue edge	Swells, cracks, turns white at edges

[1] Odors are difficult to describe, but recognizable – – use controls. (Known sample)

TABLE #5

TYPICAL PROPERTY RANGES FOR PLASTICS

THERMOSETS	Specific gravity	Transparency	Max use temp. F (no load)	HDT at 264 psi	Ten str, 1000 psi	Ten mod, 10^5 psi	Impact str, Izod, ft-lb	Flammability, in./min	Chemical resistance							Dielec constant at 60 cps	Dielec str, v/mil
									Weather res	Weak acid	Strong acid	Weak alkali	Strong alkali	Solvents			
Alkyds																	
Glass filled	2.12-2.15	No	450	400-500	4-9.5	20-28	0.6-10	0.05-0.25	R	A	A	A	A	A	5.7	250-530
Mineral filled	1.60-2.30	No	300-450	350-500	3-9	5-30	0.3-0.5	0.05-0.50	R	R	A	A	D	A	5.1-7.5	350-450
Asbestos filled	1.65	No	450	315	4.5-7	-	0.4-0.5	0.14	R	R	S	R	S	R	-	380
Syn. fiber filled	1.24-2.10	No	300-430	245-430	4.5-7	20	0.5-4.5	0.05-0.20	R	R	S	R	S	A	3.8-5.0	365-500
Allyl diglycol carbonate	1.30-1.40	Yes	212	140-190	5-6	3.0	0.2-0.4	0.35-SE	R	R	A[b]	R	R-S	R	4.4	380
Diallyl phthalates																	
Glass filled	1.61-1.78	No	300-400	330-540	6-11	14-22	0.4-15	SE - NB	R	R	S	R-S	S	R	4.3-4.6	400-450
Mineral filled	1.65-1.68	No	300-400	320-540	5-9	12-22	0.3-0.5	SE - NB	R	R	S	R-S	S	R	5.2	400-420
Asbestos filled	1.55-1.65	No	300-400	320-540	7-8	12-22	0.4-0.5	SE - NB	R	R	S	R-S	S	R	4.6-6.2	400-450
Epoxies (bis A)																	
No filler	1.06-1.40	Yes	250-500	115-500	4-13	2.15-5.2	0.2-1.0	SB	R	R	A	R	S	R-S	3.2-5.0	400-650
Graphite fiber reinf.	1.37-1.38	No	-	-	185-200	118-120	-	SE	S	R	R	R	R	R-S	-	-
Mineral filled	1.6 -2.0	No	300-500	250-500	5-15	-	0.3-0.4	SE	S	R	R	R	R	R-S	3.5-5.0	300-400
Glass filled	1.7 -2.0	No	300-500	250-500	10-30	30	10-30	SE	S	R	R-S	R	R	R-S	3.5-5.0	300-400
Epoxies (novolac)																	
No filler	1.12-1.24	No	400-500	450-500	5-11	2.15-5.2	0.3-0.7	SB	R	R	R	R	R	R	3.11-4.0	360-600
Epoxies (cycloaliphatic)																	
No filler	1.12-1.18	Yes	480-550	500-550	10-17.5	5-7	-	SB	R	R	R-A	R	R-A	R	3.6	-
Melamines																	
Cellulose filled	1.45-1.52	No	250	270	5-9	11	0.2-0.4	SE	S	R-S	D	R	D	R	6.2-7.6	350-400
Flock filled	1.50-1.55	No	250	270	7-9	-	0.4-0.5	NB	S	R-S	D	R	D	R-S	-	300-330
Asbestos filled	1.70-2.0	No	250-400	265	5-7	20	0.3-0.4	SE	S	R-S	D	S	S	R	6.4-10.2	410-430
Fabric filled	1.5	No	250	310	8-11	14-16	0.6-1.0	SE	S	R	D	R	A	R-S	7.6-12.6	250-350
Glass filled	1.8 -2.0	No	300-400	400	5-10	24	0.6-18	SE	S	R	D	R	R-S	R	9.7-11.1	170-300
Phenolics																	
Woodflour filled	1.34-1.45	No	300-350	300-370	5-9	8-17	0.2-0.6	SE	S	R-S	S-D	S-D	A	R-S	5-13	260-400
Asbestos filled	1.45-2.00	No	350-500	300-500	4.5-7.5	10-30	0.2-0.4	NB	S	R-S	S-D	S-D	A	R-S	5-20	260-360
Mica filled	1.65-1.92	No	250-300	300-350	5.5-7	25-50	0.3-0.4	NB	S	R-S	S-D	S-D	A	R-S	4.7-6	350-400
Glass filled	1.69-1.95	No	350-550	300-600	5-18	19-33	0.3-18	NB	S	R-S	S-D	S-D	A	R-S	5-7.1	140-400
Fabric filled	1.36-1.43	No	220-250	250-330	3-9	9-14	0.8-8	NB	S	R-S	S-D	S-D	A	R-S	5.2-21	200-400
Polybutadienes																	
Very high vinyl (no filler)	1.00	No	500	-	8	2	1.1	SB - SE	S	R	R	R	R	R	2.4	1800
Polyesters																	
Glass filled BMC	1.7 -2.3	No	300-350	400-450	4-10	16-25	1.5-16	SB - SE	R-E	R-A	S-A	S-A	S-D	A-D	5.3-7.3	300-420
Glass filled SMC	1.7 -2.1	No	300-350	400-450	8-20	16-25	8-22	SB - SE	R-E	R-A	S-A	S-A	S-D	A-D	-	320-400
Glass cloth reinf.	1.3 -2.1	No	300-350	400-450	25-50	19-45	5-30	SB - SE	R-E	R-A	S-A	S-A	S-D	A-D	4.1-5.5	350-500
Silicones																	
Glass filled	1.7 -2.0	No	600	600	4-6.5	10-15	3-15	SB - NB	R-S	R-S	R-S	S	S-A	R-A	3.3-5.2	200-400
Mineral filled	1.8 -2.8	No	600	600	4-6	13-18	0.3-0.4	SB - NB	R-S	R-S	R-S	S	S-A	R-A	3.5-3.6	200-400
Ureas																	
Cellulose filled	1.47-1.52	No	170	260-290	5.5-13	10-15	0.2-0.4	SE	S	R-S	A-D	S-A	D	R-S	7.0-7.5	300-400
Urethanes																	
No filler	1.1 -1.5	No & Yes	190-250	-	0.2-10	1-10	5-NB	SB - SE	R-S	S	A	S	S-A	R-S	4.0-7.5	400-500

PROPERTIES OF PLASTICS

TABLE #6

THERMOPLASTICS		Specific Gravity	Transparency	Ten. str., 1000 psi	Ten. Mod., 10^{5} psi	Imp. str. Izod^{c} ft.-lb.	Max use temp, F (no load)	HDT at 66 psi	HDT at 264 psi	Flammability^{d} in./min	Weather res	Chemical resistance^{e} W ac	S ac	W al	S al	Solv	Dielec. con. at 60 cps	Dielec. str., v/mil
ABS	GP	1.05-1.07	No	5.9	3.1	6	160-200	210-225	190-206	1.0-1.6	R-E	R	A^{b}	R	R	A^{m}-R	2.8-3.2	385
	Hi. imp.	1.01-1.06	No	4.8	2.4	7.5	140-210	210-225	188-211	1.3-1.5	R-E	R	A^{b}	R	R	A^{m}-R	2.8-3.5	300-375
	Ht. res.	1.06-1.08	No	7.4	3.9	2.2	190-230	225-252	226-240	1.3-2.0	R-E	R	A^{b}	R	R	A^{m}-R	2.7-3.5	360-400
	Trans.	1.07	Yes	5.6	2.9	5.3	130	180	165	1.2	R-E	R	A^{b}	R	R	A^{m}-R	—	—
	Self ext.	1.20	No	6.0	3.2	2.5	130-180	210-220	195	SE^{f}	R-E	R	A^{b}	R	R	A^{m}-R	2.4-5.0	370-400
Acetals	Homo	1.42	No	10	5.2	1.4	195	338	255	1.1	R^{j}	R	A	R	A-D	R	3.7	320
	Copol	1.41	No	8.8	4.1	1.2-1.6	212	316	230	1.1	R^{j}	R	A	R	R	R	3.7	500
Acrylics	GP	1.11-1.19	Yes	5.6-11.0	2.25-4.65	0.3-2.3	130-230	175-225	165-210	0.9-1.3	R	R	A^{b}	R	A	A^{m}-R	3.0-3.7	450-500
	Hi. imp.	1.12-1.16	No	5.8-8.0	2.3-3.3	0.8-2.3	140-195	180-205	165-190	0.8-1.2	R	R	A^{b}	R	R	A^{m}-R	3.5-3.9	400-500
	Self ext.	1.21-1.28	No	8.0-12.5	3.5-4.8	0.3-0.4	125-200	170-200	155-205	NB^{e}	R	R	A^{b}	R	A	A^{m}-R	3.5-5.1	400-440
	Cast	1.18-1.28	Yes	9.0-12.5	3.7-5.0	0.4-1.5	140-200	165-235	160-215	0.5-1.3	R	R	A^{b}	R	A	A^{m}-R	3.5-5.1	400-530
	Multi polymer	1.09-1.14	Yes	6.8	3.1-4.3	1.3	165-175	—	185-195	SB	E	R	A^{b}	R	S	A^{m}	3.3-3.5	495
Cellulosics	Acetate	1.23-1.34	Yes	3.0-8.0	1.05-2.55	1.1-6.8	140-220	120-209	111-195	0.5-2.0	S	S	D	S	D	D-S	3.5-7.5	250-600
	Butyrate	1.15-1.22	Yes	3.0-6.9	0.7-1.8	3.0-10.0	140-220	130-227	113-202	0.5-1.5	S	S	D	S	D	D-S	3.5-6.4	250-400
	E. cellulose	1.10-1.17	Yes	3.8	0.5-3.5	1.7-7.0	115-185	—	115-190	0.5-1.5	S	S	D	R	S	D	3.2	350-500
	Nitrate	1.35-1.40	Yes	7.8	1.9-2.2	5.7	140	—	140-160	VR^{h}	E	S	D	S	D	D	7.0-7.5	300-600
	Propionate	1.19-1.22	Yes	4.0-6.5	1.1-1.8	1.7-9.4	155-220	147-250	111-228	0.5-1.5	S	S	D	S	D	D-S	3.7-4.0	300-450
Ch. polyether		1.4	No	5.4	1.5	0.4	290	285	—	SE	R-S	R	A^{b}	R	R	R	3.0	400
Eth. copolymers	EEA	0.93	Yes	2.0	0.05	NB	190	—	—	SB^{i}	S	R	A^{b}	R	R	A-D	2.7	550
	EVA	0.94	Yes	3.6	0.02-0.12	NB	—	140-147	93	SB	S	R	A	R	R	A-D	2.50-3.16	525
Fluoropolymers	FEP	2.14-2.17	No	2.5-3.9	0.5-0.7	NB	400	158	—	NB	R	R	R	R	R	R	2.1	500-600
	PTFE	2.1-2.3	No	1.4	0.38-0.65	2.5-4.0	550	250	—	NB	R	R	R	R	R	R	2.1	400-500
	CTFE	2.10-2.15	Yes-No	4.6-5.7	1.8-2.0	3.5-3.6	350-390	258	—	NB	R	R	R	R	R	S^{n}	2.6-2.7	530-600
	PVF$_2$	1.77	No	7.2	1.7	3.8	300	300	195	NB	S	R	A^{l}	R	R	R	10.0	260
	ETFE & ECTFE	1.68-1.70	No	6.5-7.0	2-2.5	NB	300	220	160	NB	R	R	R	R	R	R	2.4-2.6	400
Methylpentene		0.83	Yes	3.3-3.6	1.3-1.9	0.95-3.8	275	—	—	1.0	E	R	A^{b}	R	R	A	—	700
Nylons	6/6	1.13-1.15	No	9-12	3.85	2.0	180-300	360-470	150-220	SE	R	R	A	R	R	R-D^{o}	4.0	385
	6	1.14	No	12.5	—	1.2	180-250	300-365	140-155	SE	R	R	A	R	R	R-A^{o}	4.0-5.3	385
	6/10	1.07	No	7.1	2.8	1.6	180	300	—	SE	R	R	A	R	R	R-A^{o}	3.9	470
	8	1.09	No	3.9		>16				SE	R	R	A	R	R	R-A^{o}	9.3	340
	12	1.01	No	6.5-8.5	1.7-2.1	1.2-4.2	175-260	—	120-130	SE-SB	R	R	A	R	R	R-A^{o}	3.6	840

TABLE #6 Continued

THERMOPLASTICS		Specific Gravity	Transparency	Ten. str., 1000 psi	Ten. Mod., 10^5 psi	Imp. str. Izod[c] ft.-lb.	Max use temp, F (no load)	HDT at 66 psi	HDT at 264 psi	Flammability[b] in./min.	Weather res	Chemical resistance[e] W ac	S ac	W al	S al	Solv	Dielec. con. at 60 cps	Dielec. str., v/mil
	Copolymers	1.08-1.14	No	7.5-11.0		1.5-19	180-250	—	130-350	0.6	R	R	A	R	R	R-A[m]	3.2-4.5	440-450
Polyesters	PET	1.37	No	10.4	—	0.8	175	240	185	SB	R	R	A[k]	R	A	R-A[o]	3.65	—
	PBT	1.31	No	8.0-8.2	3.6	1.2-1.3	280	310	130	SB	R	R	R	R	A	R	3.3-3.7	590-700
	PTMT	1.31	No	8.2	—	1.0	270	302	122	1.27	R	R	R	R	A	R	3.16	420
	Copol.	1.2	Yes	7.3	—	1.0	—	—	154	SB	—	—	—	—	—	—	—	—
Polyaryl ether		1.14	No	7.5	3.2	10	250	320	300	Yes	E	R	R	R	R	A	3.14	430
Polyaryl sulfone		1.36	No	13	3.7	2	500	—	525	SEO	Darkens	R	R	R	R	R	3.94	350
Polybutylene		0.910	No	3.8	0.26	NB	225	215	130	1.08	E	R	A[k]	R	R	—	2.25	—
Polycarbonate		1.2	Yes	9	3.45	12-16	250	270-290	265-285	SE2-SEO	R	R	A[k]	A	A	A	3.17	380
PC/ABS		1.14	No	8.2	3.7	10	220	235	220	0.90	R-E	R	A[k]	R	S	A	2.74	500
Polyethylenes	LD	0.91-0.93	No	0.9-2.5	0.20-0.27	NB	180-212	100-120	90-105	1.0	E	R	A[k]	R	R	R	2.3	480
	HD	0.95-0.96	No	2.9-5.4		0.4-14	175-250	140-190	110-130	1.0	E	R	R-A[k]	R	R	R	2.3	480
	HMW	0.945	No	2.5	1	NB	—	155-180	105-180	SB	E	R	A[k]	R	R	R	2.3	480
Ionomer		0.94-0.95	Yes	3.4-4.5	0.3-0.7	6-NB	160-180	110	100-120	SB	E	A	A[k]	R	R	R	2.4	1000
Phenylene oxide based mtls.		1.06-1.10	No	7.8-9.6	3.5-3.8	5.0	175-220	230-280	212-265	SE1-SEO	R	R	R	R	R	R-A	2.65-2.69	400-500
Polyphenylene sulfide		1.34	No	10	4.8	0.3	500	—	278	NB	R	R	A[k]	R	R	R		595
Polyimide		1.43	No	5-7.5	5.4	5-7	500	—	680	NB	—	R	R	A	A	R	4.12	310
Polypropylenes	GP	0.90-0.91	No	4.8-5.5	1.6[j]-2.2	0.4-2.2	225-300	200-230	125-140	0.7-1.0	E	R	A[k]	R	R	R	2.20-2.28	650
	Hi. imp.	0.90-0.91	No	3-5	1.3	1.5-12	200-250	160-200	120-135	1.0	E	R	A[k]	R	R	A	2.20-2.28	450-650
Propylene copolymer		0.91	No	4	1.0-1.7	1.1	190-240	185-230	115-140	SB	E	R	A[k]	R	R	R	2.25-2.30	450-600
Polystyrenes	GP	1.04-1.07	Yes	6.0-7.3	4.5	0.3	150-170	—	180-220	1.2	S	R	A[k]	R	R	D	2.45-2.65	400-600
	Hi. imp.	1.04-1.07	No	2.8-4.6	2.9-4.0	0.7-1.0	140-175	—	175-210	1.0-1.5	S	R	A[k]	R	R	D	2.45-4.75	400-500
Polysulfone		1.24	No	10.2	3.6	1.2	300	360	345	SE	S	R	R	R	R	R-A	3.14	425
Polyurethanes		1.11-1.25	No	4.5-8.4	0.1-3.5	NB	190	—	—	SB-SE	R-S	S-D	S-D	S-D	S-D	R	5.4-7.6	460
Vinyl Rigid		1.3-1.5	No-Yes	5-8	3-5	0.5-20	150-175	135-180	130-175	SE	R	R	R-S	R	R	R-A	3.2-3.6	425-1300
Vinyl Flexible		1.2-1.7	Yes & No	1-4	—	0.5-20	140-175	—	—	Yes-SE	S	R	R-S	R	R	R-A	5-6	250-800
Rigid CPVC		1.49-1.58	Yes-No	7.5-9.0	3.6-4.7	1.0-5.6	230	215-245	200-235	NB	R	R	R	R	R	R	2.8-3.6	—
PVC/acrylic		1.30-1.35	No	5.5-6.5	2.75-3.35	15	—	180	170	NB	R	R	S	R	R	A	3.9-4.0	400
PVC/ABS		1.10-1.21	No	2.6-6.0	0.8-3.4	10-15	—	—	—	SE1-SB	S	R	R-S	R	R	R-D	—	600
SAN		1.08	Yes	10-12	5.0-5.6	0.4-0.5	140-200	—	190-220	0.5-1.0	S-E	R	A	R	R	A	3.0-3.8	1775

[a] All values at room temperature unless otherwise listed. [b] Per ASTM D635. [c] Notched samples. [d] Heat deflection temperature. [e] Ac is acid and Al is alkali. R is resistant, A is attached, S is slight effects, E is embrittles and D is decomposes. [f] Self extinguishing. [g] Nonburning. [h] Very rapid. [i] Slow burning. [j] Chalks slightly. [k] By oxidizing acids. [l] By fuming sulfuric. [m] By detones, esters, and chlorinated and aromatic hydrocarbons. [n] Halogenated solvents cause swelling. [o] Dissolved by phenols and formic acid.

TABLE #7

ASSEMBLY MANUFACTURING METHODS FOR PLASTICS

	Assembly Methods									Manufacturing Methods																	
	Adhesives	Dielectric wldg.	Induction bonding	Mech. fastening	Solvent welding	Spin welding	Staking	Thermal welding	Ultrasonic wldg.	Blow molding	Calendering	Casting	Centrifugal mldg.	Compression mldg.	Extrusion	Filament winding	Injection mldg.	Laminating	Match die mldg.	Pultrusion	Rotational mldg.	Sintering	Slush mldg.	Stamping	Thermoforming	Transfer mldg.	Wet lay-up mldg.
THERMOPLASTICS																											
ABS	X	—	—	X	X	X	X	X	X	—	X	—	—	—	X	—	X	X	—	—	X	—	—	X	X	—	—
Acetals	X	—	X	X	X	X	X	X	X	X	—	—	—	—	X	—	X	—	—	—	X	—	—	—	—	—	—
Acrylics	X	—	—	X	X	X	—	—	X	X	—	X	—	—	X	—	X	X	—	—	X	—	—	—	X	—	—
Cellulosics	X	—	—	—	X	X	X	—	—	X	—	X	—	—	X	—	X	—	—	—	—	—	—	—	X	—	—
Chl. polyether	X	—	—	X	—	—	—	—	—	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	—	—	—
Ethylene copolymers	—	X	—	—	—	—	—	X	—	X	—	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	—
Fluoroplastics	X	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	X	—	—	—	—	X	—	—	X	—	—
Methylpentene	—	—	—	—	—	—	—	—	X	X	—	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	—
Nylons	X	—	X	X	—	—	X	—	X	X	—	X	—	—	X	—	X	—	—	—	X	X	—	—	—	—	—
Polyesters	X	—	—	X	X	X	X	—	X	X	—	—	—	—	X	—	X	—	—	—	—	—	—	—	X	—	—
Polyamide-imide	X	—	—	X	—	—	—	—	—	—	—	—	—	X	—	—	X	—	—	—	—	X	—	—	—	—	—
Polyaryl ether	X	—	—	X	—	—	X	—	X	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	—	—	—
Polyaryl sulfone	X	—	—	X	—	—	—	—	X	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	—	—	—
Polybutylene	—	—	—	—	—	—	X	—	X	X	—	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	—
Polycarbonate	X	—	—	X	X	X	X	X	X	X	—	—	—	—	X	—	X	—	—	—	X	—	—	X	X	—	—
Polycarbonate/ABS	X	—	—	X	X	X	X	X	X	—	—	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	—
Polyethylenes	X	X	X	X	—	X	X	X	X	X	—	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	—
Ionomer	—	X	—	—	—	—	—	X	—	X	—	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	—
Phenylene oxide based materials	X	—	—	X	X	X	X	X	X	—	—	—	—	—	X	—	X	—	—	—	—	—	—	X	X	—	—
Polyphenylene sulfide	X	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—
Polyimide	X	—	—	X	—	—	—	—	—	—	—	—	—	X	—	—	—	X	—	—	—	X	—	—	—	—	—
Polypropylenes	X	X	X	X	—	X	X	X	X	X	—	—	—	—	X	—	X	—	—	—	—	—	—	X	X	—	—
Propylene copolymers	X	X	X	X	—	X	—	X	—	X	—	—	—	—	X	—	X	—	—	—	—	—	—	—	X	—	—
Polystyrenes	X	—	X	X	X	X	X	X	X	X	—	—	—	—	X	—	X	—	—	—	X	—	—	—	X	—	—
Polysulfone	X	—	—	X	—	—	X	—	X	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	X	—	—
Vinyls	X	X	X	X	—	—	—	X	—	X	X	—	—	—	X	—	X	—	—	—	X	—	X	—	X	—	—
PVC/Acrylic alloy	X	—	X	X	—	—	—	—	X	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	X	—	—
PVC/ABS alloys	X	X	—	—	—	—	—	X	—	—	X	—	—	—	X	—	X	—	—	—	—	—	—	—	X	—	—
Styrene acrylonitrile	X	—	X	X	X	X	X	X	X	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	X	—	—
THERMOSETS																											
Alkyds	X	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	X	—	—	—	—	—	—	—	—	X	—
Allyl diglycol carbonate	X	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Diallyl phthalate	X	—	—	X	—	—	—	—	—	—	—	X	—	X	—	—	X	—	—	—	—	—	—	—	—	X	—
Epoxies	X	—	—	X	—	—	—	—	—	—	—	X	X	X	—	X	X	X	X	X	—	—	—	—	—	X	X
Melamines	X	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	X	—	—	—	—	—	—	—	—
Phenolics	X	—	—	X	—	—	—	—	—	—	—	X	—	X	—	—	X	X	—	—	—	—	—	—	—	X	—
Polybutadienes	X	—	—	—	—	—	—	—	—	—	—	X	—	X	—	—	—	X	—	—	—	—	—	—	—	X	X
Polyesters	X	—	—	X	—	—	—	—	—	—	—	X	X	X	—	X	X	X	X	X	—	—	—	—	—	X	X
Silicones	X	—	—	X	—	—	—	—	—	—	—	X	—	X	—	—	X	X	—	—	—	—	—	—	—	X	—
Ureas	X	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	X	—
Urethanes	X	—	—	X	—	—	—	—	—	—	—	X	—	X	—	—	X	X	—	—	—	—	—	—	—	—	—

Table #8 Hardness Conversion Tables

Brinell 10 mm 3000 kg			*Rockwell number*				*Superficial Rockwell*			*Vickers*	*Scleroscope*	*Tensile strength*	*MOH 10*
Indentation (mm)	*Standard*	*Tungsten carbide*	*A 60 kg-Brale*	*B 100 kg-1/16 in Ball*	*C 150 kg-Brale*	*D 100 kg-Brale*	*15N 15 kg*	*30N 30 kg*	*45N 45 kg*	*Pyramid diamond*	*Number*	*× 10³ psi*	*Scale*
2.25		745	84.1		65.3	74.8	92.3	82.2	72.2	840	91		
2.30		710	83.0		63.3	73.3	91.5	80.4	70.2	780	87		
2.35		682	82.2		61.7	72.0	91.0	79.0	68.5	737	84		
2.40		653	81.2		60.0	70.7	90.2	77.5	66.5	697	81		
2.45		627	80.5		58.7	69.7	89.6	76.3	65.1	667	79	323	8.0
2.50		601	79.8		57.3	68.7	89.0	75.1	63.5	677	77	309	
2.55		578	79.1		56.0	67.7	88.4	73.9	62.1	640	75	297	
2.60		555	78.4		54.7	66.7	87.8	72.7	60.6	591	73	285	7.5
2.65		534	77.8		53.5	65.8	87.2	71.6	59.2	569	71	274	
2.70		514	76.9		52.1	65.0	86.7	70.7	58.0	547	70	263	
2.75	495	495	76.3		51.0	63.8	85.9	69.4	56.1	528	68	253	
2.80	477	477	75.6		49.6	62.7	85.3	68.2	54.5	508	66	243	
2.85	461	461	74.9		48.5	61.7	84.7	67.2	53.2	491	65	235	7.0
2.90	444	444	74.2		47.1	60.8	84.0	65.8	51.5	472	63	225	
2.95	429	429	73.4		45.7	59.7	83.4	64.6	49.9	455	61	217	
3.00	415	415	72.8		44.5	58.8	82.8	63.5	48.4	440	59	210	
3.05	401	401	72.0		43.1	57.8	82.0	62.3	46.9	425	58	202	
3.10	388	388	71.4		41.8	56.8	81.4	61.1	45.3	410	56	195	
3.15	375	375	70.6		40.4	55.7	80.6	59.9	43.6	396	54	188	6.5
3.20	363	363	70.0		39.1	54.6	80.0	58.7	42.0	383	52	182	
3.25	352	352	69.3	110.0	37.9	53.8	79.3	57.6	40.5	372	51	176	
3.30	341	341	68.7	109.0	36.6	52.8	78.6	56.4	39.1	360	50	170	
3.35	331	331	68.1	108.5	35.5	51.9	78.0	55.4	37.8	350	48	166	
3.40	321	321	67.5	108.0	34.3	51.0	77.3	54.3	36.4	339	47	160	
3.45	311	311	66.9	107.5	33.1	50.0	76.7	53.3	34.4	328	46	155	
3.50	302	302	66.3	107.0	32.1	49.3	76.1	52.2	33.8	319	45	150	6.0
3.55	293	293	65.7	106.0	30.8	48.3	75.3	51.2	32.4	309	43	145	
3.60	285	285	65.3	105.5	29.9	47.6	75.0	50.3	31.2	[illegible]	42	141	
3.65	277	277	64.6	104.5	28.8	46.7	74.4	49.3	29.9	292	41	137	
3.70	269	269	64.1	104.0	27.6	45.9	73.7	48.3	28.5	284	40	133	
3.75	262	262	63.6	103.0	26.6	45.0	73.1	47.3	27.3	276	39	129	
3.80	255	255	63.0	102.0	25.4	44.2	72.5	46.2	26.0	269	38	126	
3.85	248	248	62.5	101.0	24.2	43.2	71.7	45.1	24.5	261	37	122	5.5
3.90	241	241	61.8	100.0	22.8	42.0	70.9	43.9	22.8	253	36	118	
3.95	235	235	61.4	99.0	21.7	41.4	70.3	42.9	21.5	247	35	115	
4.00	229	229	60.8	98.2	20.5	40.5	69.7	41.9	20.1	241	34	111	
4.05	223	223		97.3	18.8					234			
4.10	217	217		96.4	17.5					228	33	105	
4.15	212	212		95.5	16.0					222		102	
4.20	207	207		94.6	15.2					218	32	100	
4.25	201	201		93.8	13.8					212	31	98	
4.30	197	197		92.8	12.7					207	30	95	
4.35	192	192		91.9	11.5					202	29	93	
4.40	187	187		90.7	10.0					196		90	
4.45	183	183		90.0	9.0					192	28	89	5.0
4.50	179	179		89.0	8.0					188	27	87	
4.55	174	174		87.8	6.4					182		85	
4.60	170	170		86.8	5.4					[illegible]	26	83	
4.65	167	167		86.0	4.4					75		81	
4.70	163	163		85.0	3.3					171	25	79	
4.80	156	156		82.9	0.9					163		76	
4.90	149	149		80.8						156	23	73	4.5
5.00	143	143		78.7						150	22	71	
5.10	137	137		76.4						143	21	67	
5.20	131	131		74.0						137		65	
5.30	126	126		72.0						132	20	63	
5.40	121	121		69.8						127	19	60	
5.50	116	116		67.6						122	18	58	
5.60	111	111		65.7						117	15	56	

ANSWERS TO STUDENT PROBLEMS

CHAPTER I

Section 2:

1. Fusing
2. Electric arc
3. Electrode
4. Electric current
5. Helmet, gauntlet gloves, safety glasses, long sleeves, cap

Section 3:

1. Acetylene with oxygen
2. Brittle
3. Flow
4. 3 PSI, 3 PSI
5. No. 3
6. Gloves, tinted goggles, cap, treated coveralls
7. Horizontal
8. Gas
9. Lap, fillet, butt, tube to plate

Section 4:

1. 427°C
2. Melting
3. Hottest spot
4. Flux
5. Clean
6. Brass alloy
7. Oxidizers

Section 5:

1. L-1, 25 PSIG, 5 PSIG
2. 1/8 inch

CHAPTER II

Section 1:

1. Thermo, thermosetting
2. Ease of lighting, whether self-extinguishing, odor, nature of flame, behavior of material
3. 9,000 - 12,000 PSI

Section 3:

1. Adhesives, staking, induction bonding, ultrasonic welding, mechanical fasteners
2. Vacuum forming, mat lay-up with roller, spray and mat lay-up
3. Hot gas
4. Methyl ethyl ketone
5. R Elastomeric adhesive, E 100% Reactive - Epoxy
6. Elastomeric adhesive, rubber
7. 8,000 to 12,000 SFPM
8. Moderately easy to light, self-extinguishing, smells like burnt wool, burns with a blue flame and yellow top, material melts, drips and froths
9. 300 to 800 SFPM

CHAPTER III

Section 2:

1. Screwed gate valve, screwed globe valve, screwed check valve, screwed tee, screwed-90° elbow, screwed union, screwed cap
2. Screwed, socket welded, flanged raised face, soldered

Section 3:

	Name	Application
a)	Threaded reducer	Change pipe size
b)	Threaded cap	Cap off pipe leg
c)	Threaded cross	Connect four lines
d)	Threaded 45° elbow	Turn at 45° angle
e)	Threaded 90° elbow	Turn 90°
f)	Threaded union	Have a point to separate pipe without rotation
g)	Threaded check valve	Control fluid flow
h)	Threaded gate valve	Turn flow on and off
i)	Threaded glove valve	Control flow and shut off
j)	Threaded coupling	Connect two threaded pipes
k)	Threaded lateral	Connect branch line with minimum pressure drop
l)	Threaded pipe plug	Plug a threaded port
m)	Threaded concentric reducer	Connect two different line sizes
n)	Threaded eccentric reducer	Connect two line sizes with both pipes at same elevation on one side
o)	Threaded tee	Connect three pipe sections at right angles

Section 4:

1. B = 6' - 3.0" + .8" = 69.8 inches
   C = 4' - 3.0" + .8" = 45.8 inches

2. B = 6' - 3" = 69 inches

   C = 4' - 3" = 45 inches

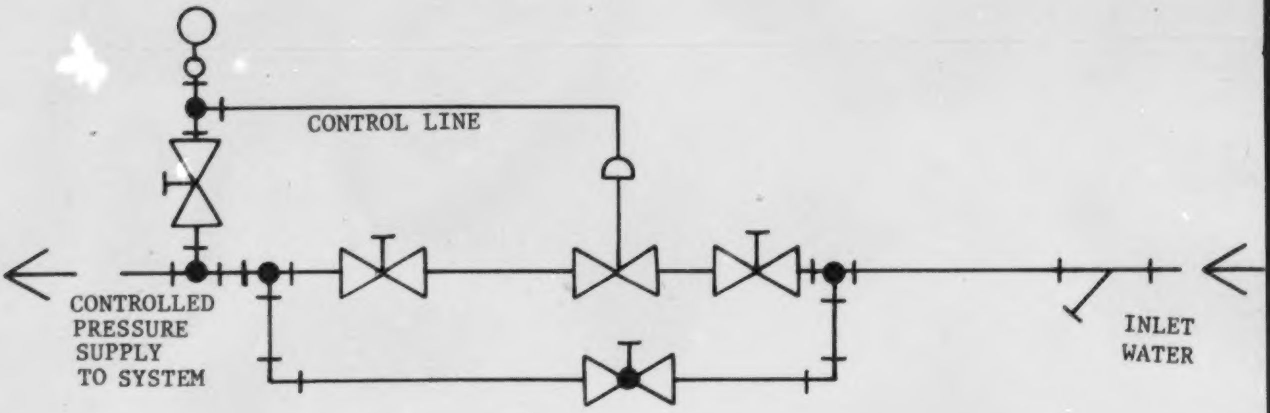
Chapter III Cont.

Section 5:

1. Methyl ethyl ketone solvent or heat gun welding
2. Fast assembly, thinner tubing can be used, lower cost connections
3. Pressure, temperature
4. Disassembled
5. Solvent bonding, hot knife

Section 6:

1. Compression, flare, flanged
2. A.N. American National, Military Spec.
3. Socket weld"O" ring
4.



CHAPTER IV

Section 1:

1. Impact strength, tensile strength, coefficient of friction, yield strength, fatigue endurance limit
2. 30,000,000 psi
3. a) 36,000 lb/in^2, b) 69,000 lb/in^2, c) 15%, d) 20,000,000 psi
4. a) .15, b) 14.4 Newtons, c) 96 Newtons, d) 4.55 lb

Section 2:

1. ASME, ASTM, American Standards, SAE, sales literature
2. Telephone yellow pages, Thomas register, company purchasing department
3. Number, size, place for cost, delivery date, shipment delivery destination, date ordered, item specifications, possible suggested suppliers

CHAPTER V

1. Plating, hot dip, chemical conversion
2. Zinc
3. Alkyd silicone

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